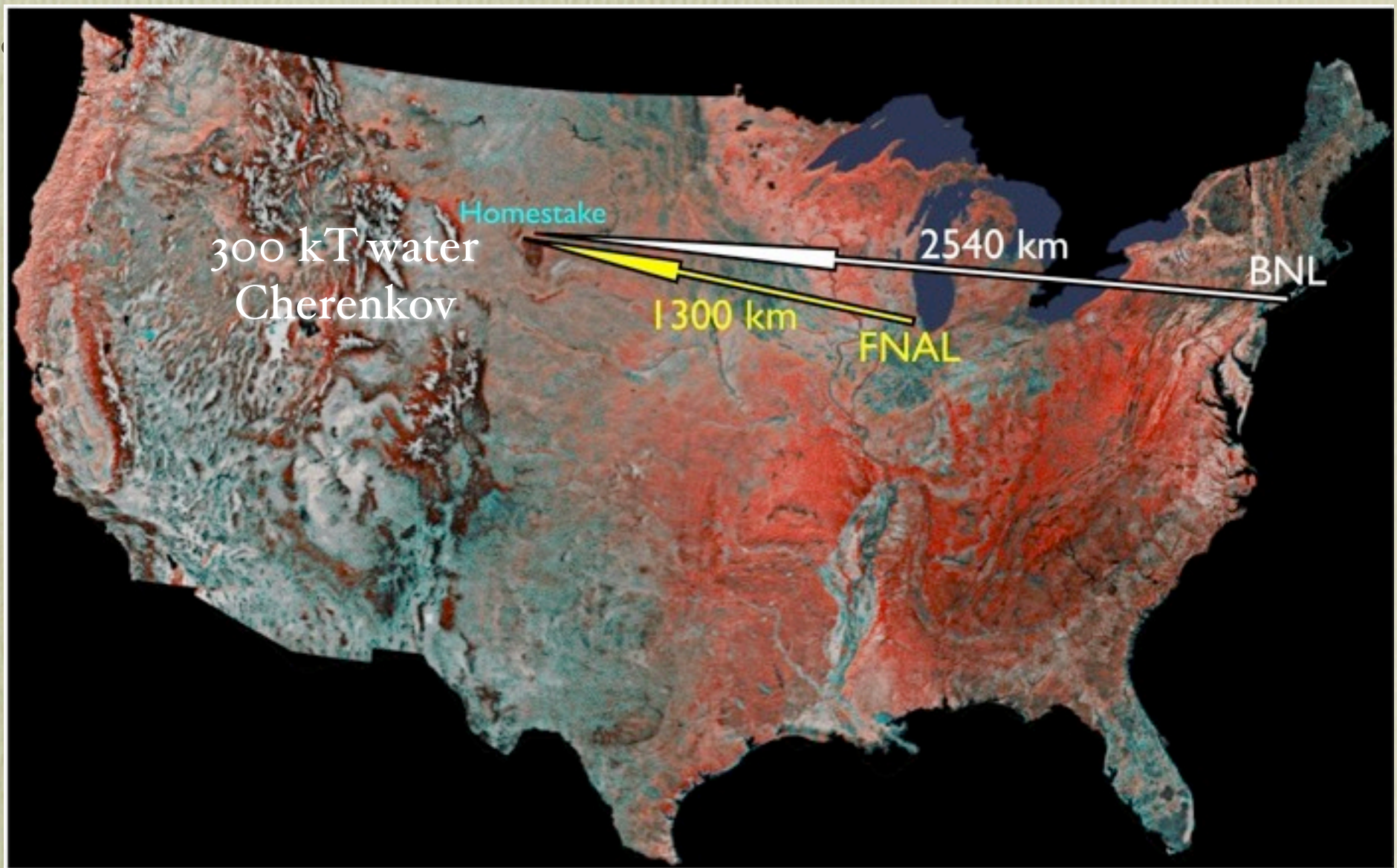
FNAL to DUSEL long baseline experiment

- Milind Diwan (BNL, USA) 7/6/2009, Santa Fe INFO09 Workshop



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Convergence of Interests

New scientific discoveries in neutrino physics have set the scale of the project.

Technology for an intense neutrino beam is almost ready; perhaps needs some investment in SRF

The same scale detector is needed for non-accelerator physics.

Technology of the water Cherenkov detector is ready for the next step. There is impetus to get LARtpc ready also.

High Energy Physics interest comes from the linkage with GUT scale phenomena. The last mixing angle, the mass hierarchy, and CP have GUT scale implications

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Outline

- Physics considerations.
  - Strategy, Rate, Sensitivity, Detector Performance calculations.
- Technical summary of the project.
  - Intensity/Beam/Detector design considerations.
- Recent progress on organization.
  - Collaboration, schedule, funds, meetings.

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LBNE references

Documents	Workshops and reviews
NNN99 proceedings, editors C.K. Jung and M. Diwan Extra longbaseline..., W.Marciano, arXiv:hep-ph/0108181, Aug2001 D. Beavis, et al., hep-ex/0205040, 2002 Very longbaseline..., M. Diwan, et al., BNL69395, hep-ex/0211001 Megaton Modular..detector, M. Diwan, hep-ex/0306053, 2003 Int. J. Mod. Phys. A18:4039,2003 Phys. Rev. D 68: 012002,2003	NNN99, NUSL workshop in Lead Oct2001, NESS2002, StonyBrook 2002, HQL2004 Presentation to SAGENAP, March 12, 2002 **Initial ideas**
The AGS based superneu..., Alessi et al., BNL-73210-2004-IR,2004 The case for a superneu.., M.Diwan, hep-ph/0407047 Spectrum...,S.Kahn, PAC-2005-RPPT059, 2005. FNAL Proton driver, hep-ex/0509019 Neutrino Matrix Report, 2004. Backg. study..., Yanagisawa et al., AIP conf. proc. 944:92-106, 2007.	PAC2003, NuFACT05, FNAL proton driver workshop 2004 APS multi-divisional study: Joint BNL/UCLA/APS workshop, Snowmass2004, BNL/UCLA workshop 2004, 2005. PAC2005 HEPAP Future Facilities Subcommittee, Feb. 2003 **Development**
Preliminary cost & design..., BNL-76798-2006-IR, hep-ex/0608023 US longbaseline study,... FNAL-0801,BNL-77973,arXiv:0705.4396 NSF Homestake S1, S2, S3 proposals. NSF S4 proposal for detector development. Report on depth..., BNL-81896-IR, FNAL-TM-2424, LBNL-1348E http://nwg.phy.bnl.gov/fnal-bnl	NNN series of workshops, NUFACT workshops, UDIG 2008 workshop, DUSEL workshops, US long baseline study meetings, Homestake PAC, 2006, BNL PAC 2006 NUSAG, 2006, HEPAP 2006, 2007 P5 committee Feb, 2008 **Proposal**

- Genesis: Detector needs a neutrino beam, but what distance ? Why bother with longer distances than the first maximum ?

Brief review of oscillations

Assume a 2×2 neutrino mixing matrix.

$$\begin{pmatrix} \nu_a \\ \nu_b \end{pmatrix} = \begin{pmatrix} \cos(\theta) & \sin(\theta) \\ -\sin(\theta) & \cos(\theta) \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \end{pmatrix}$$

$$\begin{aligned} \nu_a(t) &= \cos(\theta)\nu_1(t) + \sin(\theta)\nu_2(t) \\ P(\nu_a \to \nu_b) &= |<\nu_b|\nu_a(t)>|^2 \\ &= \sin^2(\theta)\cos^2(\theta)|e^{-iE_2 t} - e^{-iE_1 t}|^2 \end{aligned}$$

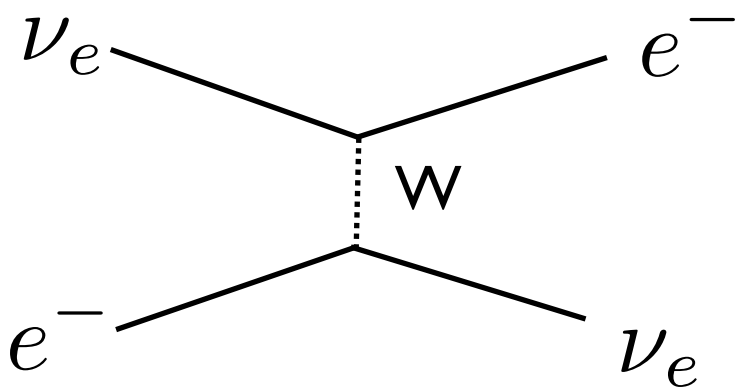
Sufficient to understand most of the physics:

$$P(\nu_a \to \nu_b) = \sin^2 2\theta \sin^2 \frac{1.27((m_2^2 - m_1^2)/eV^2)(L/km)}{(E/GeV)}$$

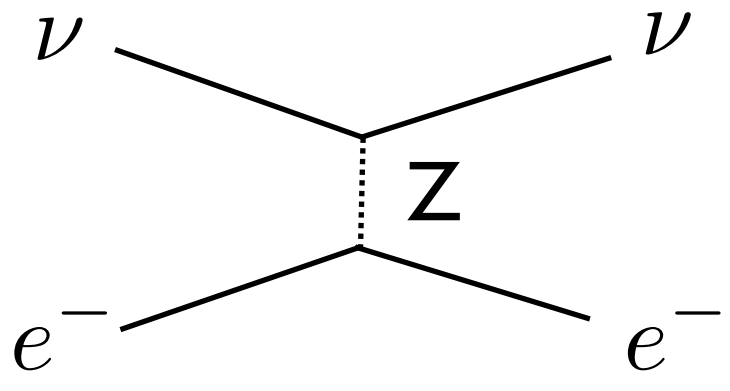
$$P(\nu_a \to \nu_a) = 1 - \sin^2 2\theta \sin^2 \frac{1.27(\Delta m^2/eV^2)(L/km)}{(E/GeV)}$$

Oscillation nodes at $\pi/2, 3\pi/2, 5\pi/2, \ldots$ $(\pi/2)$: $\Delta m^2 = 0.0025 eV^2$, $E = 1 GeV$, $L = 494 km$.

Matter effect arises from a difference in interaction amplitudes between different species of neutrinos.



Charged Current
for electron type only



Neutral Current
for all neutrino types

Additional potential for ν_e ($\bar{\nu}_e$): $\pm\sqrt{2}G_F N_e$

N_e is electron number density.

Oscillations in presence of matter

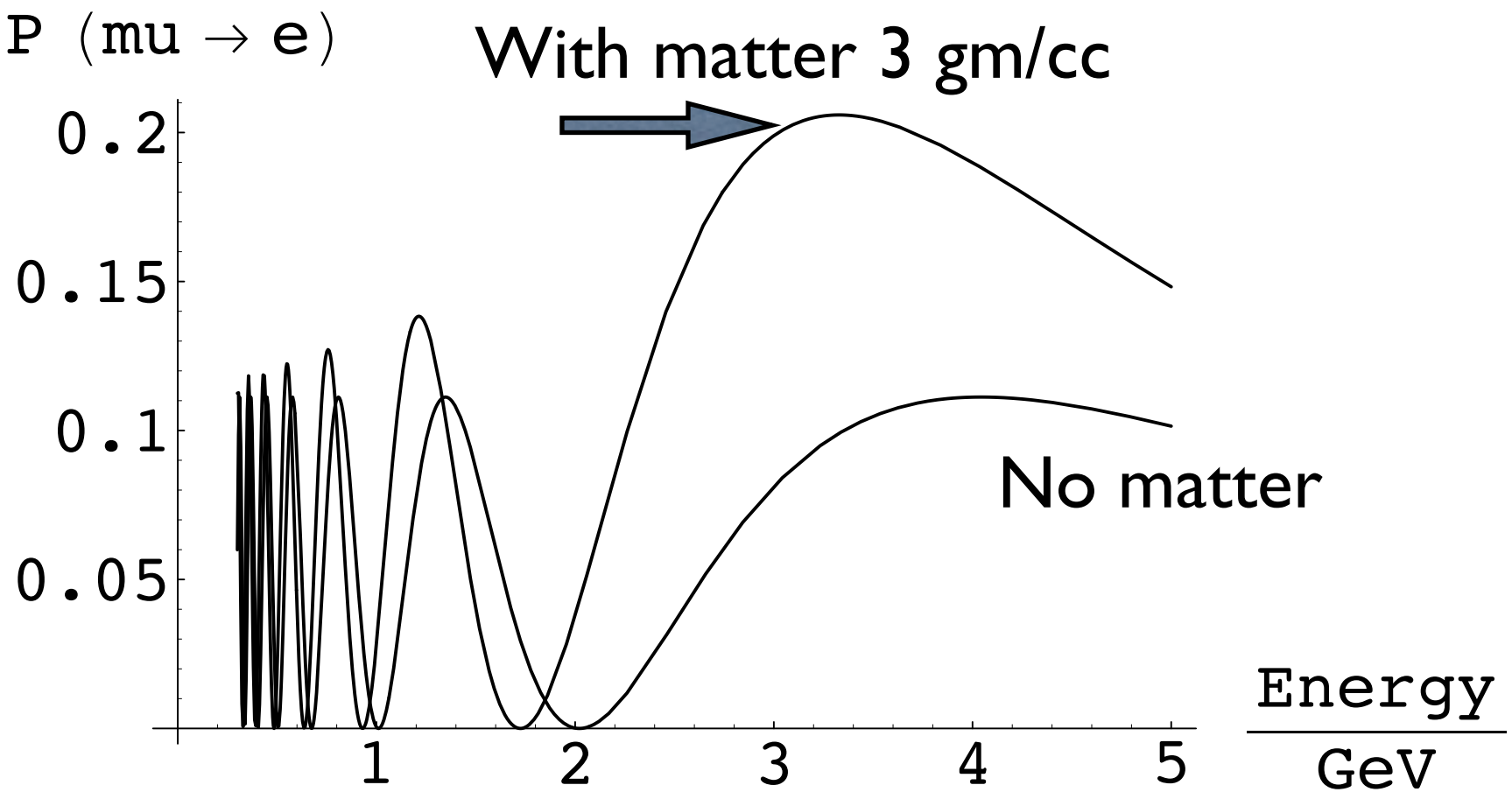
$$i\frac{d}{dx}\nu_f = R_\theta H(\nu_m) + H_{mat}(\nu_f)$$

$$i\frac{d}{dx}\begin{pmatrix}\nu_e\\ \nu_\mu\end{pmatrix} = \frac{1}{4E}\left(R_\theta\begin{pmatrix}m_1^2 & 0\\ 0 & m_2^2\end{pmatrix}R_\theta^T + 2E\begin{pmatrix}\sqrt{2}G_F N_e & 0\\ 0 & -\sqrt{2}G_F N_e\end{pmatrix}\right)\begin{pmatrix}\nu_e\\ \nu_\mu\end{pmatrix} \quad (3)$$

$$P_{\mu\to e} = \frac{\sin^2 2\theta}{(\cos 2\theta - a)^2 + \sin^2 2\theta}\times\sin^2\frac{L\Delta m^2}{4E}\sqrt{(a-\cos 2\theta)^2+\sin^2 2\theta}$$

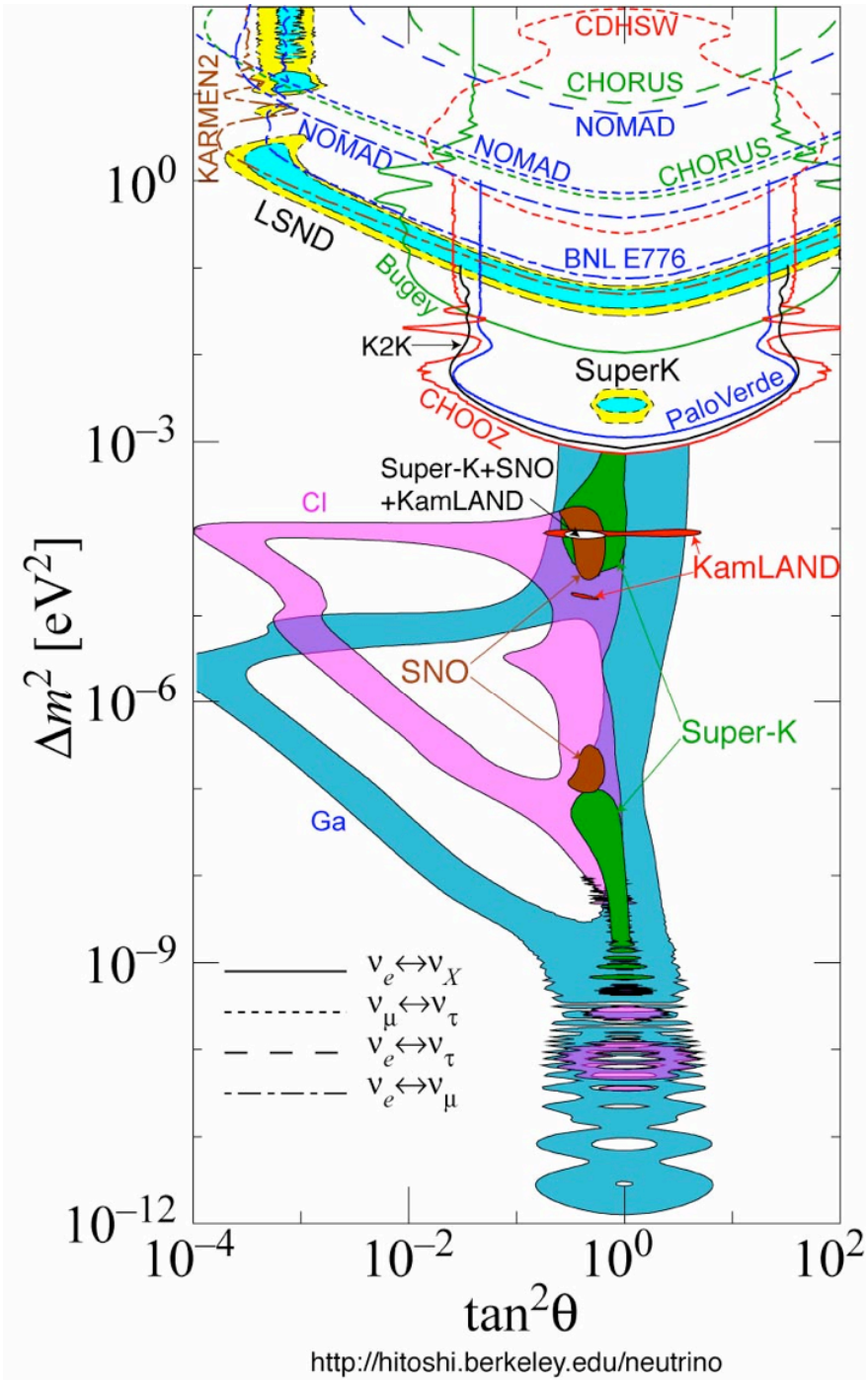
$$\begin{aligned} a &= 2\sqrt{2}EG_F N_e/\Delta m^2 \\ &\approx 7.6\times 10^{-5}\times D/(gm/cc)\times E_\nu/GeV/(\Delta m^2/eV^2) \end{aligned} \quad (4)$$

Matter effect with 2-neutrinos



Osc. probability: 0.0025 eV^2, L= 2000 km, Theta=10deg

Summary of experiments



$\theta_{atmospheric}$ (primarily θ_{23})

θ_{solar} (primarily θ_{12})

Phenomenology of $\nu_\mu \rightarrow \nu_e$

The Mixing Matrix

Atmospheric × Cross-Mixing × Solar

$$U = \begin{bmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{bmatrix} \times \begin{bmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{bmatrix} \times \begin{bmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\times \begin{bmatrix} e^{i\alpha_1/2} & 0 & 0 \\ 0 & e^{i\alpha_2/2} & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

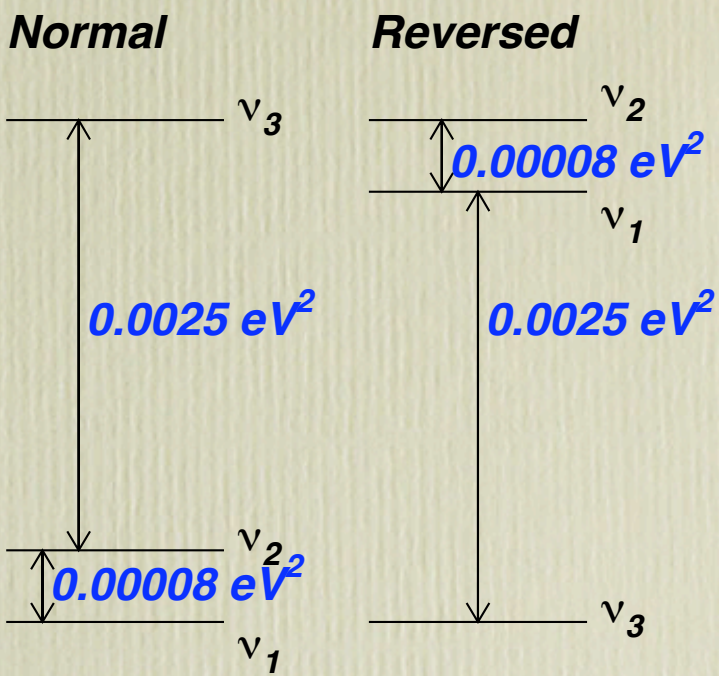
$c_{ij} \equiv \cos\theta_{ij}$
$s_{ij} \equiv \sin\theta_{ij}$

Majorana ~~CP~~ phases

$\theta_{12} \approx \theta_{sol} \approx 34°$, $\theta_{23} \approx \theta_{atm} \approx 37\text{-}53°$, $\theta_{13} \lesssim 10°$

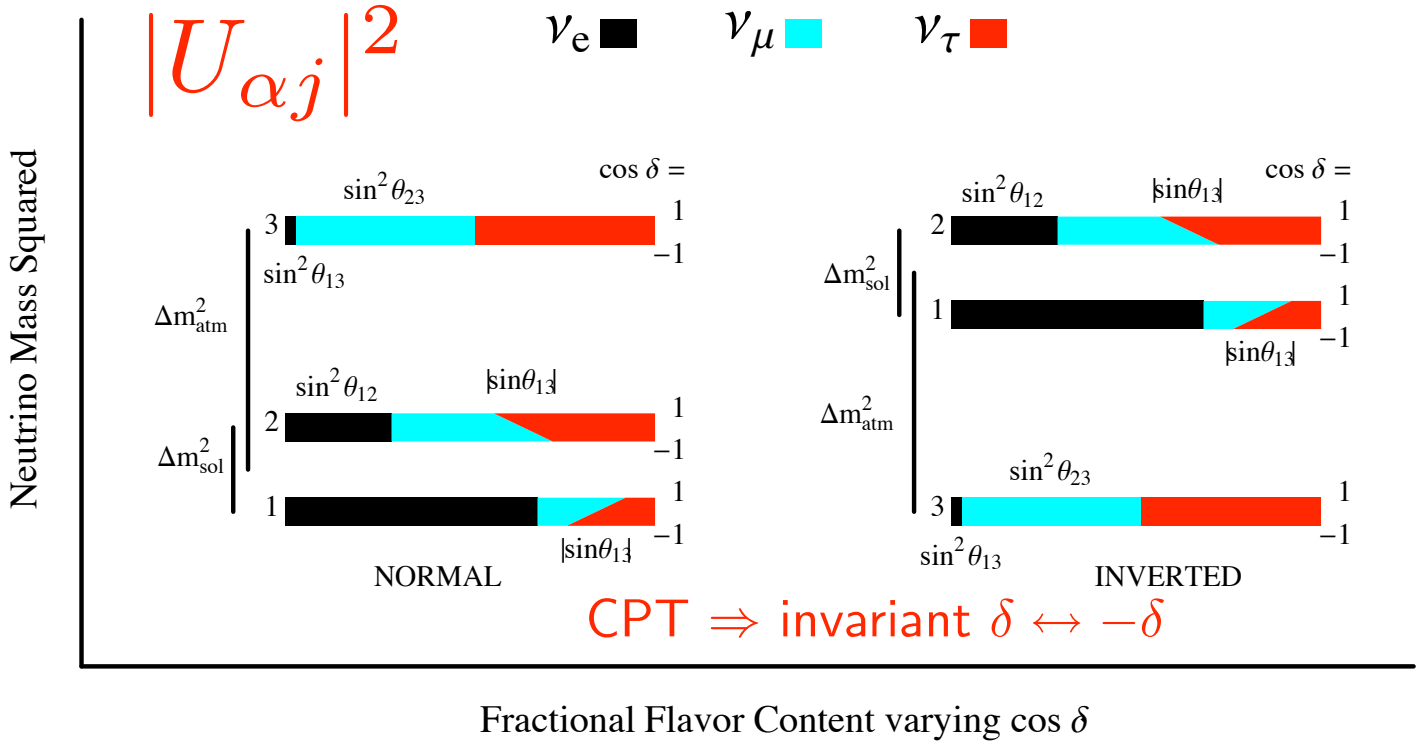
δ would lead to $P(\overline{\nu}_\alpha \rightarrow \overline{\nu}_\beta) \neq P(\nu_\alpha \rightarrow \nu_\beta)$. ~~CP~~

mass-squares



Difference in mass squares: $(m_2^2\text{-}m_1^2)$

Oscillation nodes at $\pi/2, 3\pi/2, 5\pi/2, \ldots$ $(\pi/2)$: $\Delta m^2 = 0.0025 eV^2$,
$E = 1GeV$, $L = 494km$. Solar : L~15000km



$\delta m^2_{sol} = +7.6 \times 10^{-5}\ eV^2$

$|\delta m^2_{atm}| = 2.4 \times 10^{-3}\ eV^2$

$|\delta m^2_{sol}|/|\delta m^2_{atm}| \approx 0.03$

$\sin^2\theta_{12} \sim 1/3$

$\sin^2\theta_{23} \sim 1/2$

$\sin^2\theta_{13} < 3\%$

$\sqrt{\delta m^2_{atm}} = 0.05\ eV < \sum m_{\nu_i} < 0.5\ eV = 10^{-6} * m_e$

$0 \leq \delta < 2\pi$

One Global Fit:

Dominated by

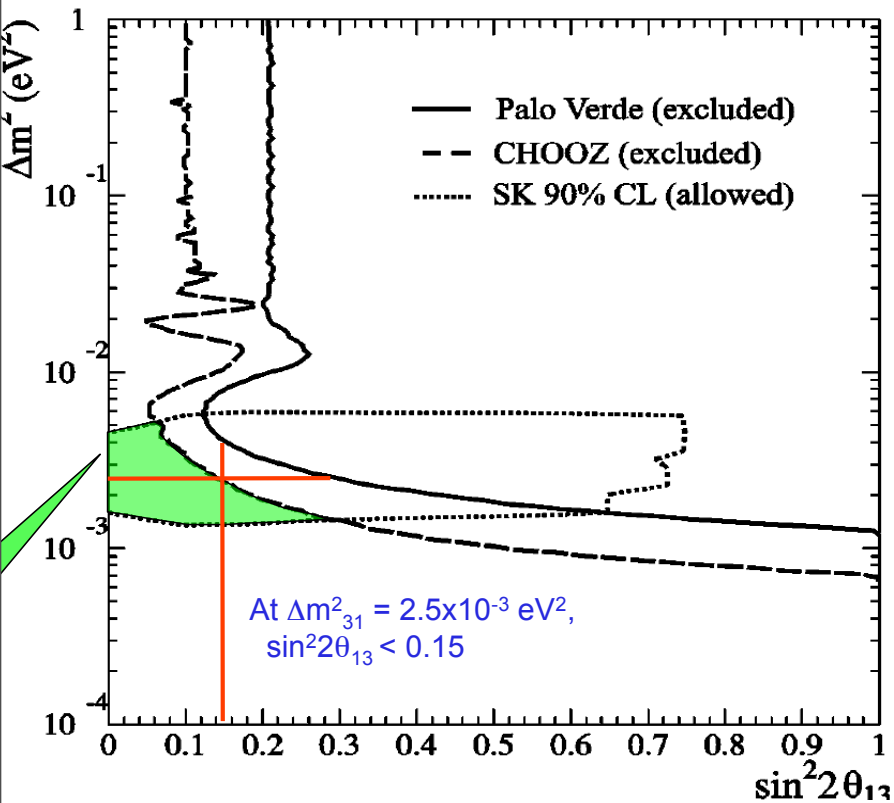
parameter	best fit	2σ	3σ
Δm^2_{21} $[10^{-5}\mathrm{eV}^2]$	$7.65^{+0.23}_{-0.20}$	7.25–8.11	7.05–8.34
$\lvert\Delta m^2_{31}\rvert$ $[10^{-3}\mathrm{eV}^2]$	$2.40^{+0.12}_{-0.11}$	2.18–2.64	2.07–2.75
$\sin^2\theta_{12}$	$0.304^{+0.022}_{-0.016}$	0.27–0.35	0.25–0.37
$\sin^2\theta_{23}$	$0.50^{+0.07}_{-0.06}$	0.39–0.63	0.36–0.67
$\sin^2\theta_{13}$	$0.01^{+0.016}_{-0.011}$	≤ 0.040	≤ 0.056

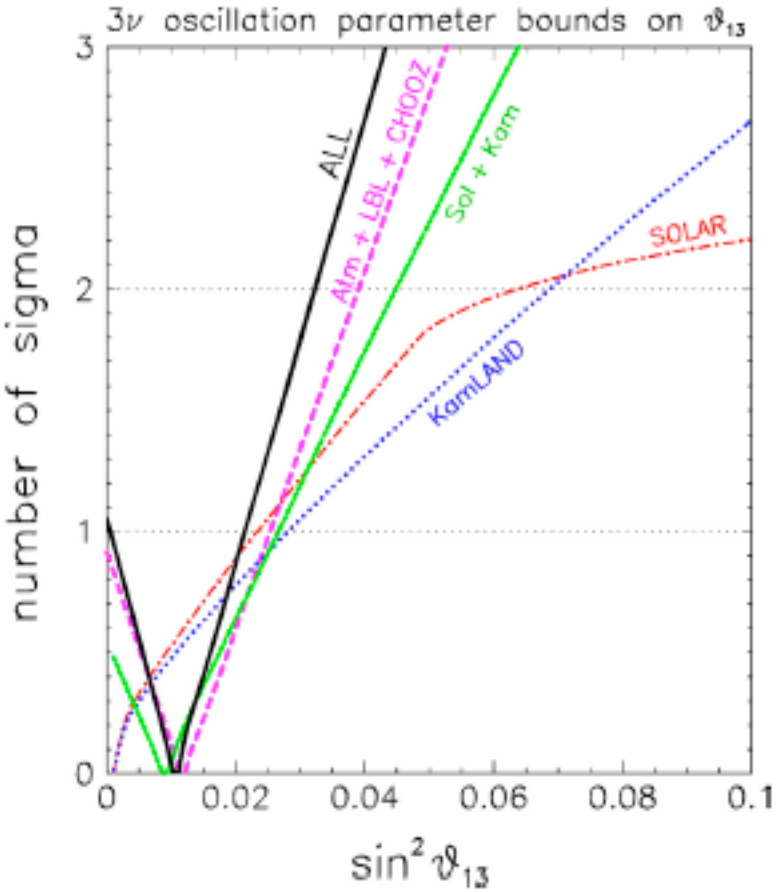
KamLAND
MINOS
SNO
SuperK
Chooz

arXiv:0808.2016

Global fit

Current direct search limits





Fogli *et al.*, Venice ν-oscillation workshop(2008) and arXiv:0806.2649 [hep-ph]

Balantekin & Yilmaz, J. Phys. G **35**, 075007 (2008) (arXiv:0804.3345 [hep-ph]).

$\nu_\mu \to \nu_e$ with matter effect

Approximate formula (M. Freund)

matter effect ~E

$$P(\nu_\mu \to \nu_e) \approx \sin^2\theta_{23}\frac{\sin^2 2\theta_{13}}{(\hat{A}-1)^2}\sin^2((\hat{A}-1)\Delta)$$

~7500 km no CPV. magic bln

$$+\alpha\frac{8J_{CP}}{\hat{A}(1-\hat{A})}\sin(\Delta)\sin(\hat{A}\Delta)\sin((1-\hat{A})\Delta)$$

CPV term approximate dependence ~L/E

$$+\alpha\frac{8I_{CP}}{\hat{A}(1-\hat{A})}\cos(\Delta)\sin(\hat{A}\Delta)\sin((1-\hat{A})\Delta)$$

$$+\alpha^2\frac{\cos^2\theta_{23}\sin^2 2\theta_{12}}{\hat{A}^2}\sin^2(\hat{A}\Delta)$$

solar term

linear dep.

$$J_{CP} = 1/8\sin\delta_{CP}\cos\theta_{13}\sin 2\theta_{12}\sin 2\theta_{13}\sin 2\theta_{23}$$

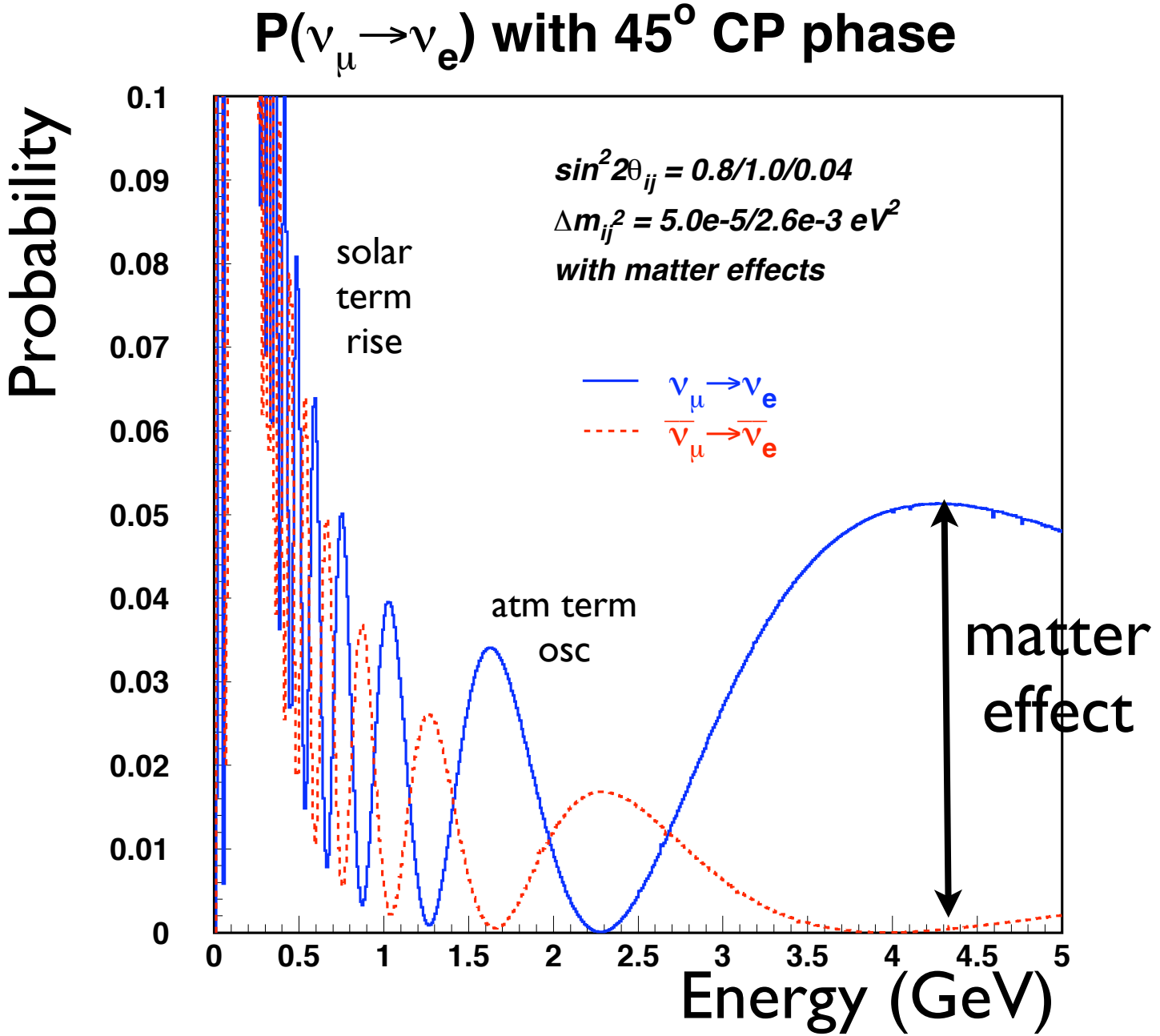
$$I_{CP} = 1/8\cos\delta_{CP}\cos\theta_{13}\sin 2\theta_{12}\sin 2\theta_{13}\sin 2\theta_{23}$$

$$\alpha = \Delta m^2_{21}/\Delta m^2_{31},\ \Delta = \Delta m^2_{31}L/4E$$

$$\hat{A} = 2VE/\Delta m^2_{31} \approx (E_\nu/GeV)/11 \text{ For Earth's crust.}$$

CP asymmetry grows as th13 becomes smaller

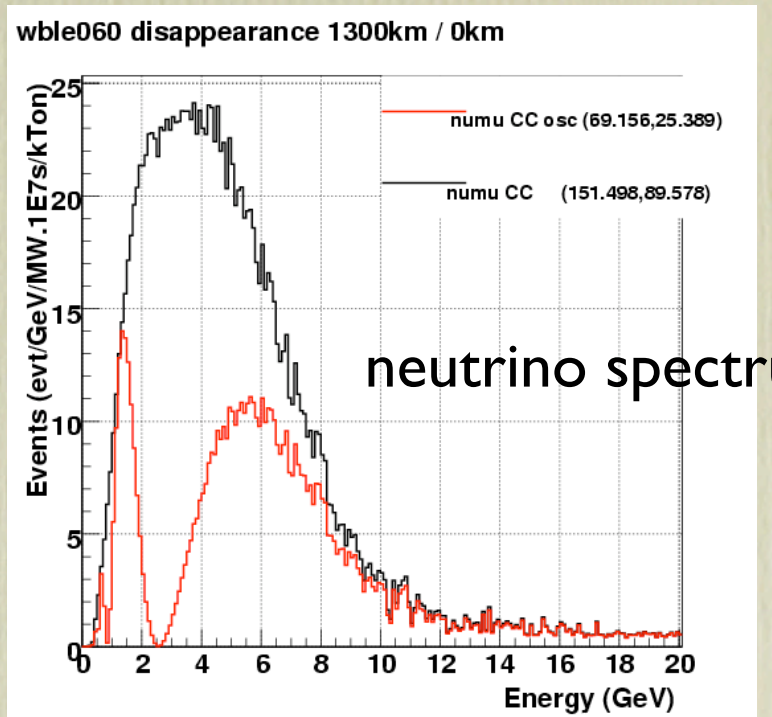
Example of oscillation probability with matter effects L=2540 km



Event rate for FNAL to Homestake

Evt rate: 1 MW for 3 yrs ★

Event type	300kT, 120 GeV 0.5 deg.	300kT, 60 GeV 0 deg.
Numu CC no osc	161820	272693
Numu CC with osc	68220	124479



neutrino spectrum

High precision $\sin^2 2\theta_{23}$, Δm^2_{32}

- Important (esp. $\theta_{23} \sim 45$ deg.) with possibility of new physics.
- Either 120 GeV or 60 GeV beam can be used: two oscillation nodes.
- Measurement dominated by systematics (see hep/0407047) (~1%)

★ yr~2×10^7 sec

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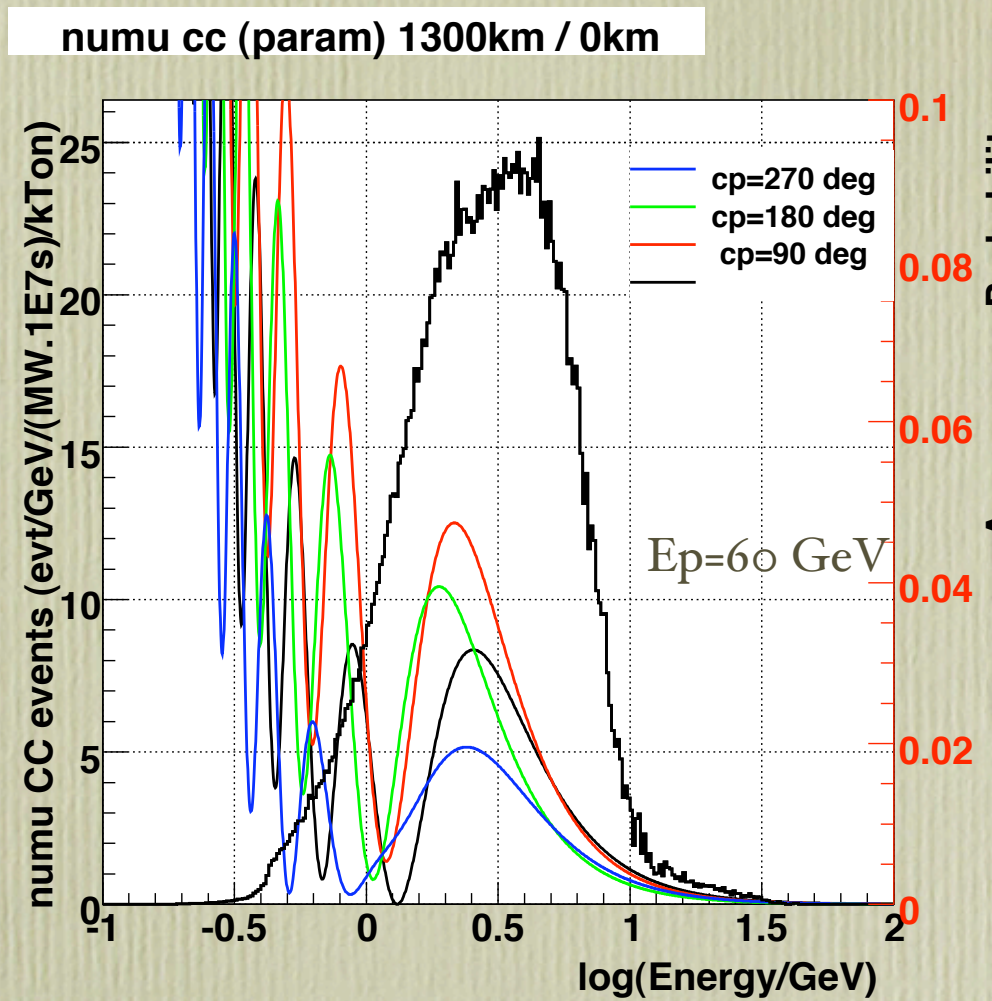
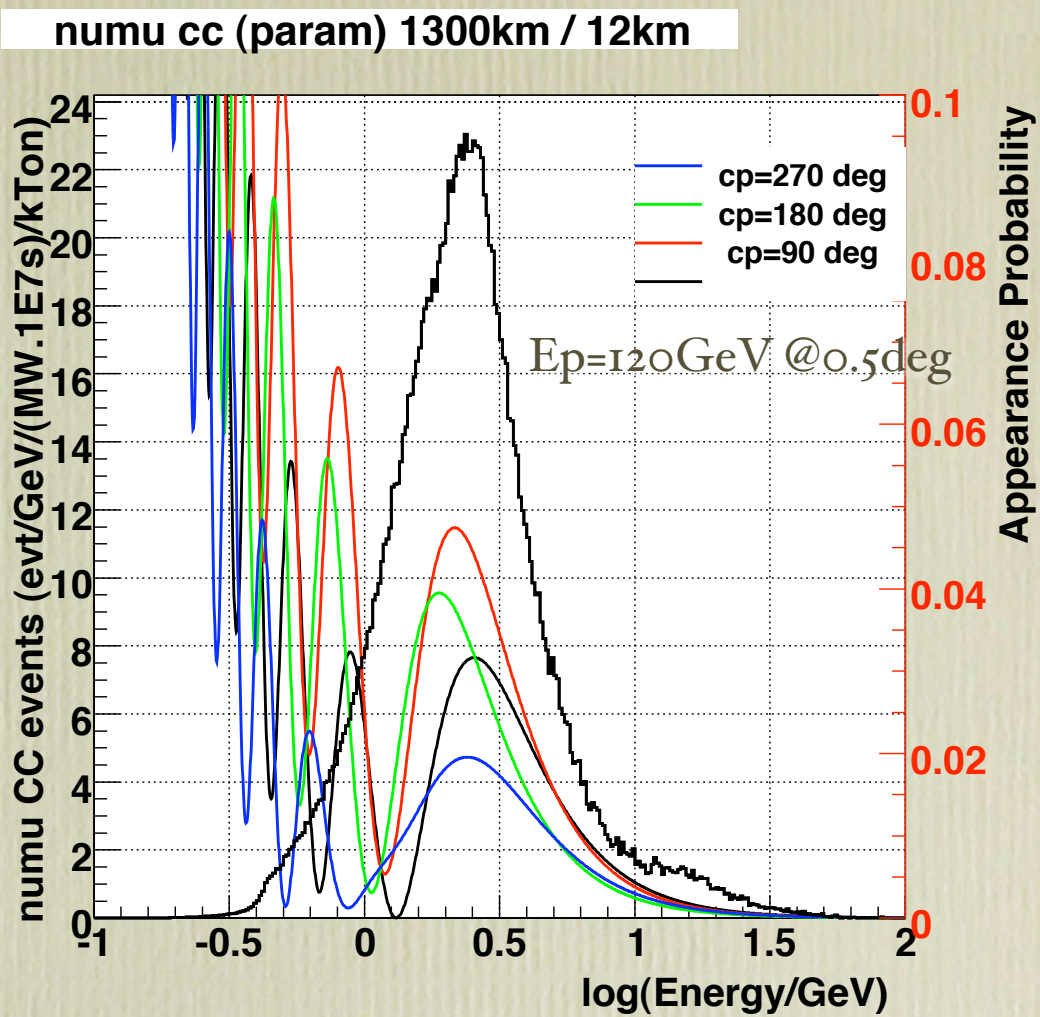
Spectra FNAL to DUSEL (WBLE:wide band low energy)





- 60 GeV at 0deg: CCrate: 14 per (kT*10^20 POT)
- 120 GeV at 0.5deg:CCrate: 17 per(kT*10^20POT)

Work of M. Bishai and B. Viren using NuMI simulation tools

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Key Event Rate in 100kT*MW*10^7

5.2e20 POT @ 120 GeV

$$\nu_\mu \rightarrow \nu_e$$

$\Delta m^2_{21,31} = 8.6 \times 10^{-5}, 2.5 \times 10^{-3} eV^2$ $\sin^2 2\theta_{12,23} = 0.86, 1.0$ $\sin^2 2\theta_{13} = 0.02$

$$\delta_{CP}$$

	$sgn(\Delta m^2_{31})$	0 deg	+90 deg	180 deg	-90 deg	nue backg
WBLE NU (1300km)	+	87	48	95	134	47
WBLE NU (1300km)	-	39	19	51	72	
WBLE ANU (1300km)	+	20	27	15	7.2	17
WBLE ANU (1300km)	-	38	52	33	19	

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Who is afraid of θ_{13} ?

$\sin^2 2\theta_{13}$	Events 0CP, (+)	Frac. diff. wrt (-)	Frac. diff. wrt 90CP
0.02	87	0.55	0.45
0.1	607	0.55	0.23

Matter effect

CP effect

- Normalization: 1MW*100kT*10^7
- Significance for CP violation is different from matter effect. For large θ_{13} it is only weakly dependent on θ_{13}

The key experimental factor

- Huge (>100kT) detector with high efficiency.
- MW class beam helps, but need the above detector first.

Scientific strategy

- The Study: A very large detector and an intense beam needed for the next steps for θ13, mass ordering, and CP violation from the standard 3-generation scenario.
- The Study: Program should have broad physics capability: nucleon decay, supernova detection, astrophysical neutrinos.
- Conventional wisdom: Experimental set up with a large matter effect, such as for 1300 km, is more sensitive to possible new physics.
- For neutrino mixing the experiment must have internal redundancy to check 3-gen CP violation and get hints of new physics if they are there.

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Detector design considerations.

- Need ~100kT of fiducial mass with good efficiency. Much larger if lower efficiency. At this mass scale cosmic ray rate becomes the driving issue for detector placement and design.

$\sin^2 2\theta_{13} = 0.02$ signal-50 evts/yr

Event type	100 kTon	100 kTon
Proton Beam Energy	120 GeV	60 GeV
Angle	0.5^o	0^o
CC ν_μ No Oscillations	27000	45000
CC ν_μ With Oscillations	11400	21000

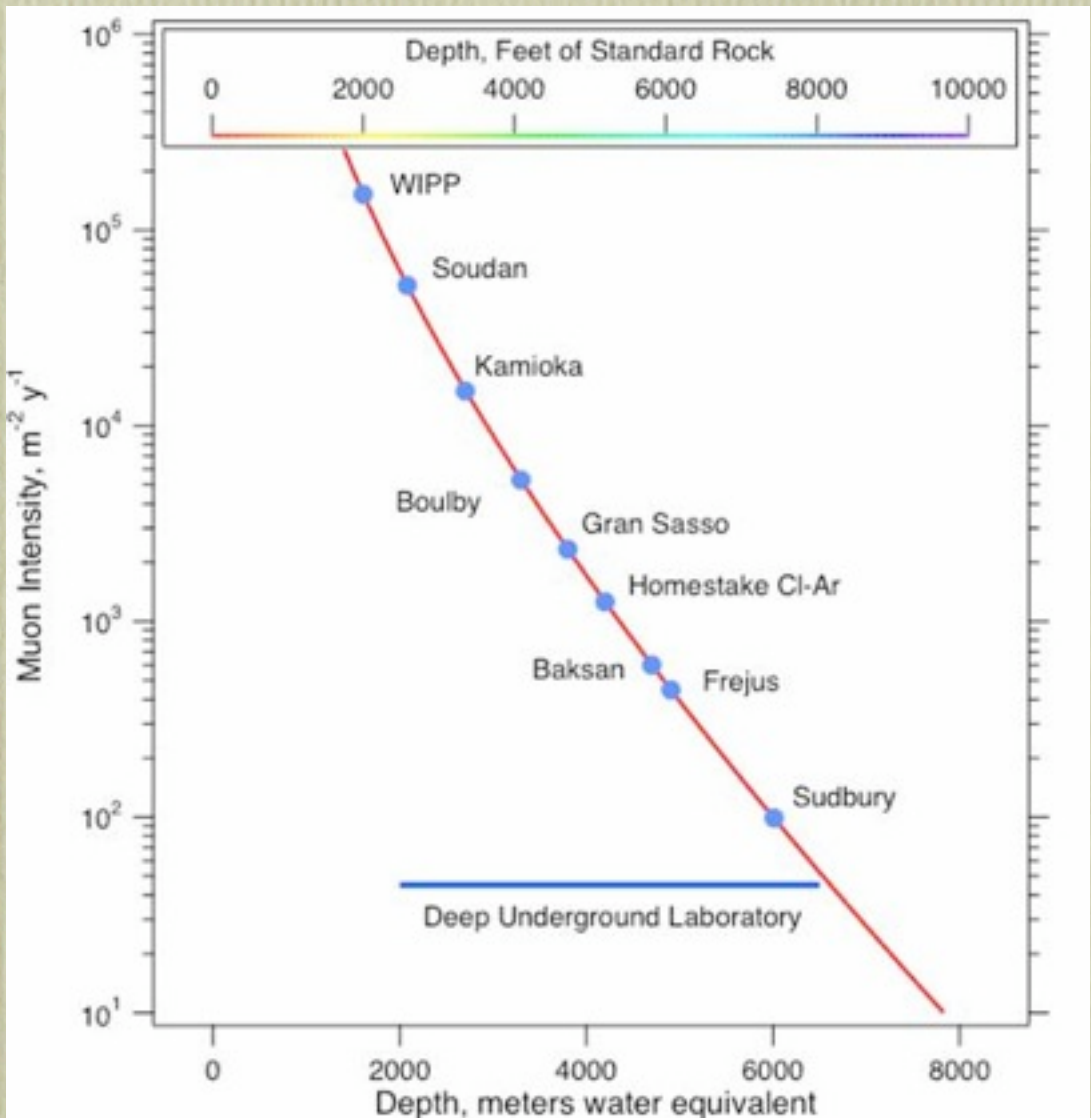
Ref: BNL-81896-2008

Rate(Hz)	In-time cosmics/yr	Depth (mwe)
500 kHz	5×10^7	0
3 kHz	300,000	265
400 Hz	40,000	880
5 Hz	500	2300
1.3 Hz	130	2960
0.60 Hz	60	3490
0.26 Hz	26	3620
0.09 Hz	DUSEL depth 9	4290

Cosmic rate in 50m h/dia detector in 10μs for 10^7 pulses

If detector is placed on the surface it must have cosmic rejection for muons $\sim 10^8$ and for gammas$\sim 10^4$beyond accelerator timing.=> fully active fine grained detector.

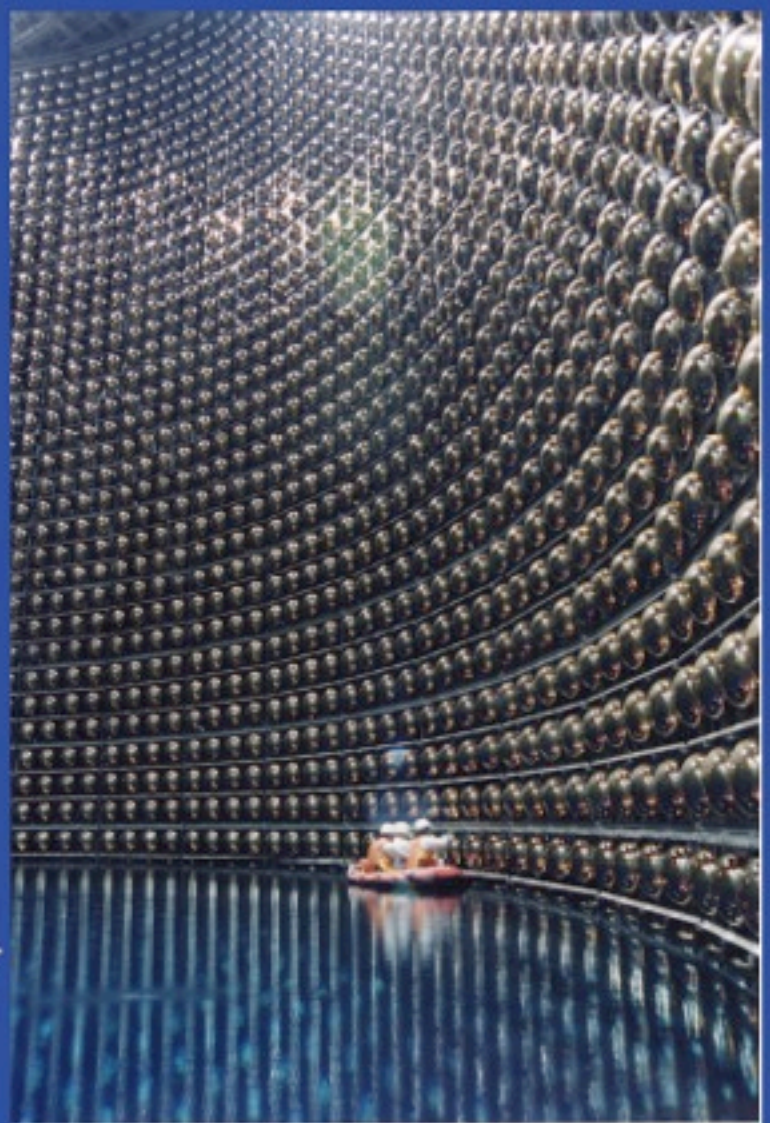
Next key Experimental factor

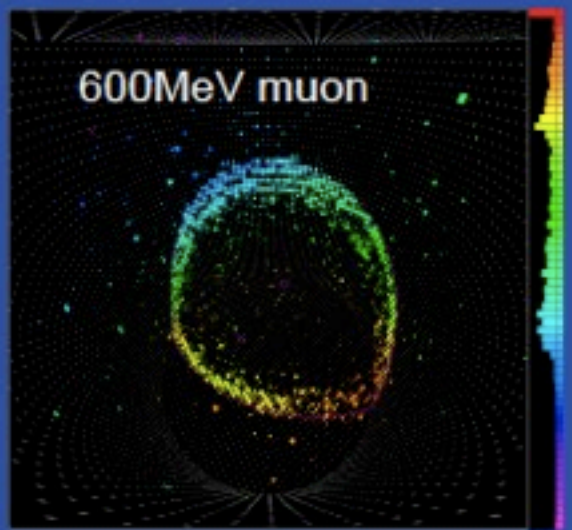


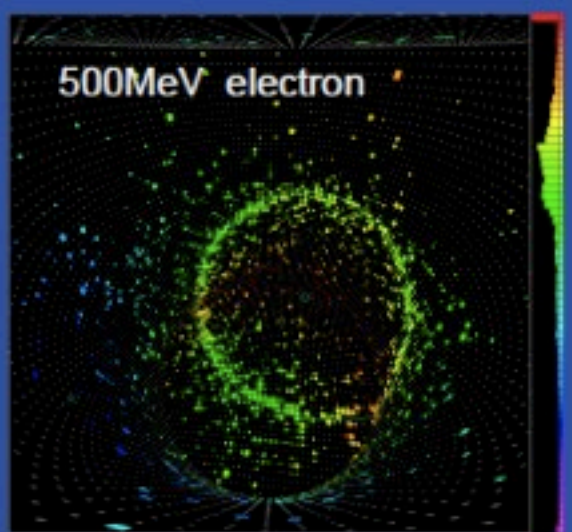
- Detector of 100 kTon scale needs to be at least at 1000 mwe; even for accelerator physics.
- A very fine grained detector such as LARtpc could be shallower, but needs thorough examination and experience.
- In any case, the shallow will means loss of non-accelerator science. Shallow need not mean less expensive after fiducial volume loss.
- The scientific judgement behind placing such a facility at any depth needs debate.

Far Detector : Water Cerenkov

- Super-K
  - 13K 20” PMT
  - 40% coverage
  - 50 kT total mass
  - 39 m diameter
  - 42 m height
- LBNE
  - 60 K 10” PMT per 100kT FV module (25%)
  - ~55 m diameter
  - ~60 m height







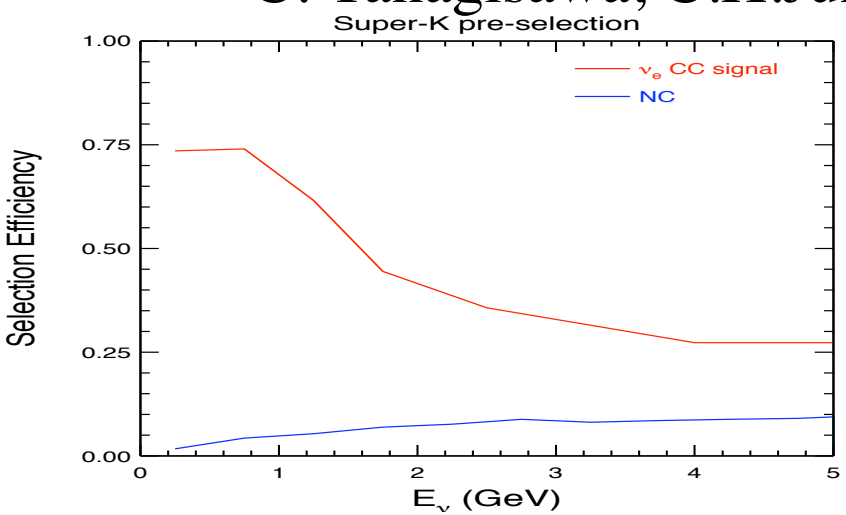
Fermilab

Water Cerenkov Simulation

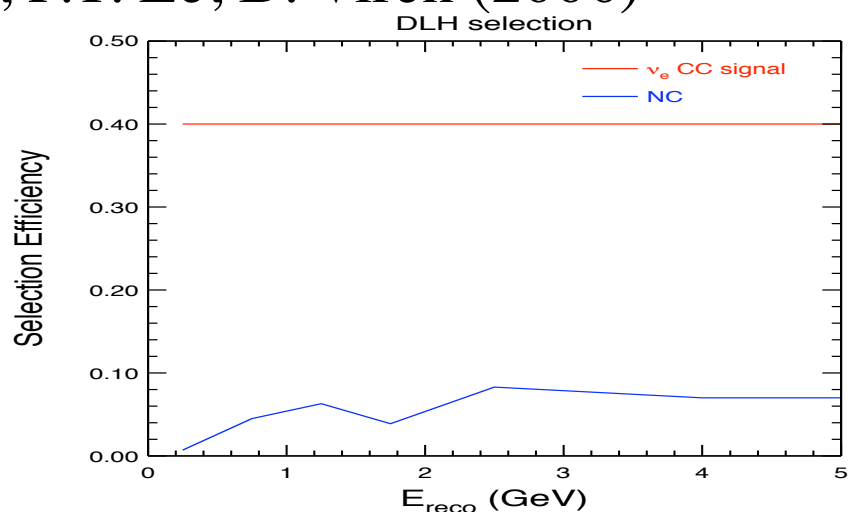
The ν_{atm} GEANT simulation of SuperKamiokande is used.

An π^0 reconstruction algorithim called "Pattern Of Light Fit" is used as input to a likelihood (DLH) analysis to reconstruct $\pi^0 \rightarrow \gamma\gamma$ by looking for the 2nd ring. Independent studies by Chiaki Yanagisawa for FNAL-DUSEL WBB and Fanny Dufour for T2KK produce similar efficiency for signal and background.

C. Yanagisawa, C.K.Jung, P.T. Le, B. Viren (2006)



Standard Super-K pre-selection efficiencies



DLH selection efficiencies (Chiaki Y.)

WCe. energy dependent efficiencies and smearing implemented in GLoBeS.

Detector performance

- Current work focusses on using only the quasi-elastic events: 15-20% of total for oscillation physics for a water Cherenkov detector.
- Selection of quasielastics with sufficient purity has been demonstrated (previous slide).
- Remarkable work from mini-boone demonstrates that perhaps more of the events can be used also. (Zeller talk at BNL)
- For the LARtpc, we are assuming that all CC events can be used. But this needs much more experience and work.

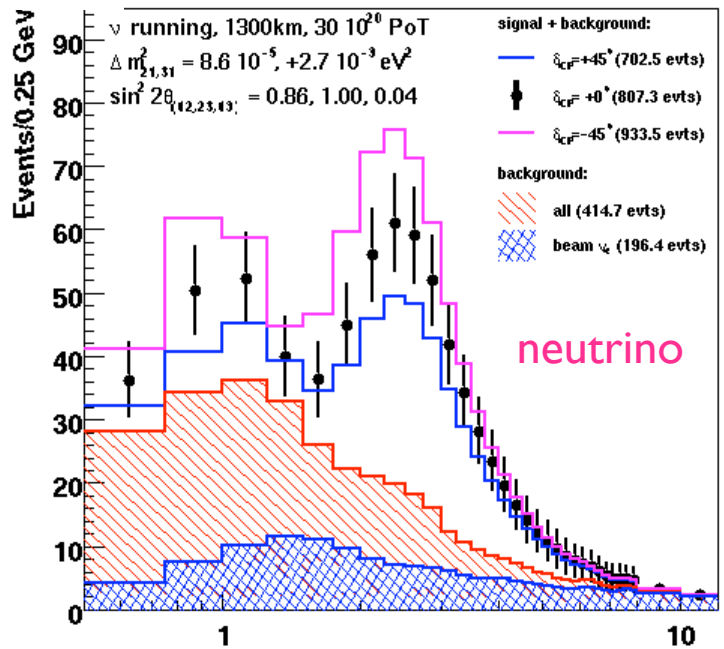
Electron neutrino appearance spectra

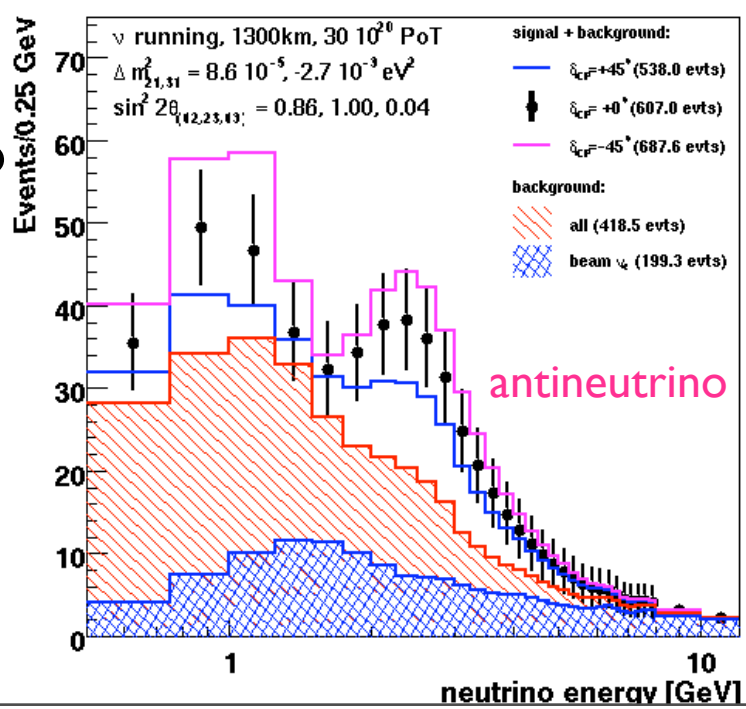
$\sin^2 2\theta_{13} = 0.04$, **300kT WCe.**, WBLE 120 GeV, 1300km, 30E20 POT.

$(-\delta_{cp} = -45°, -\delta_{cp} = +45°)$

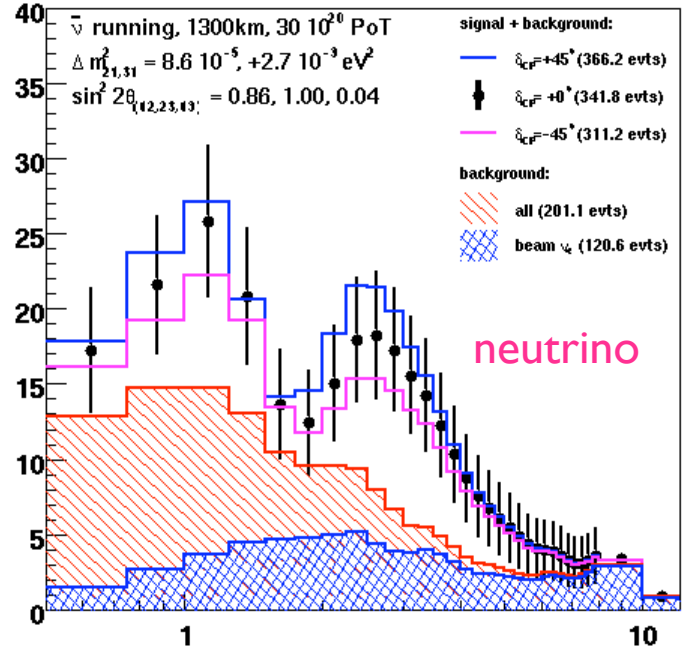
- All background sources are included.
- S/B ~ 2 in peak.
- NC background about same as beam nue backg.
- For normal hierarchy sensitivity will be from neutrino running.
- For reversed hierarchy anti-neutrino running essential.
- Better efficiency at low energies expected with higher PMT counts.

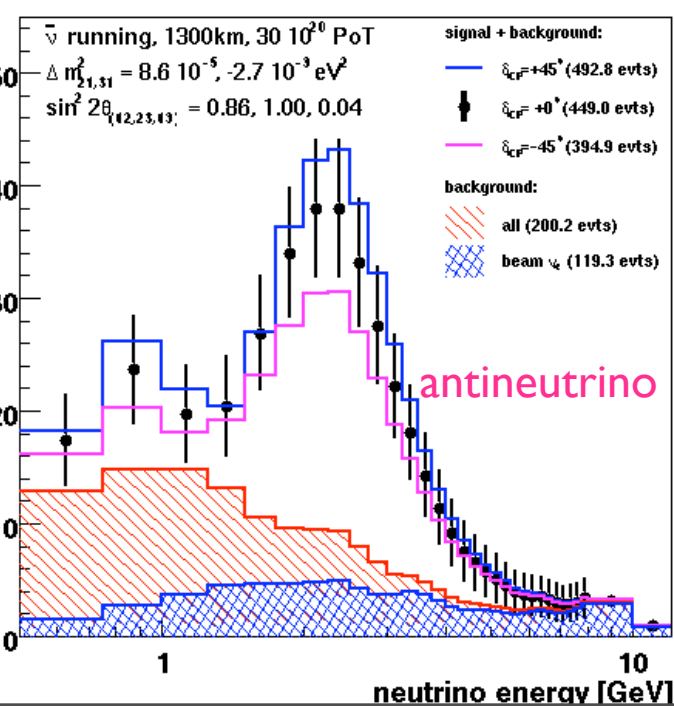
Normal





Reversed





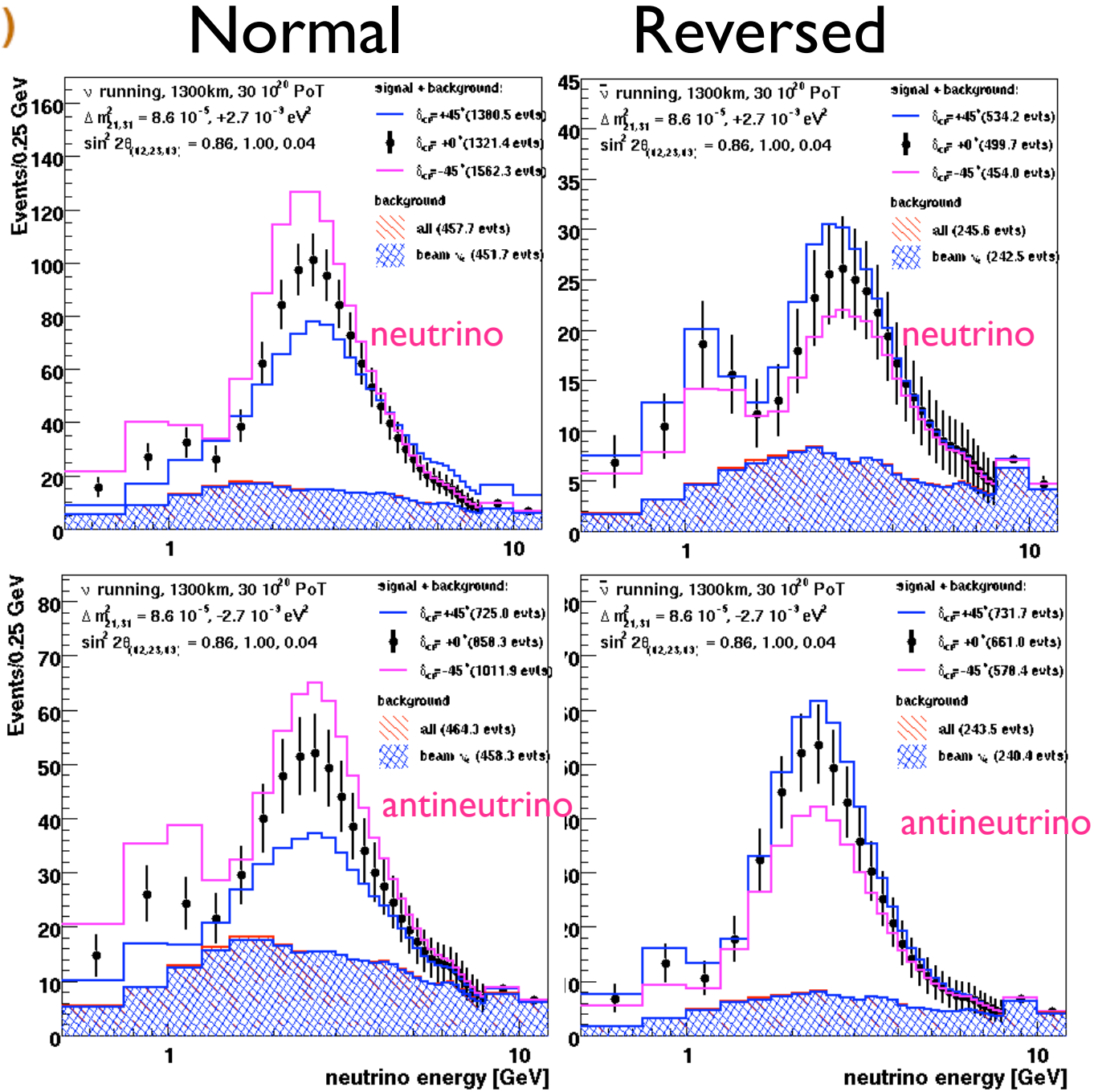
Electron neutrino appearance spectra

$\sin^2 2\theta_{13} = 0.04$, **100kT LAr.**, **WBLE 120 GeV, 1300km, 30E20 POT.**

$(-\delta_{cp} = -45°, -\delta_{cp} = +45°)$

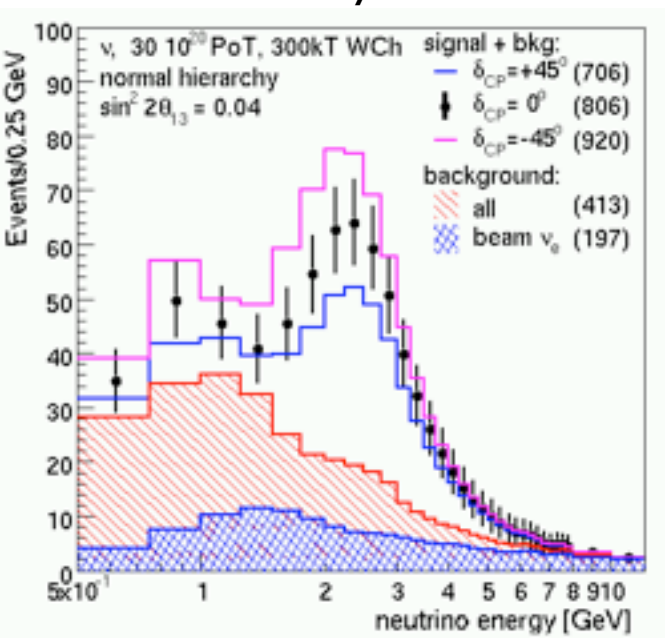
- LAR assumptions
- 80% efficiency on electron neutrino CC events.
- sig(E)/E = 5%/sqrt(E) on quasielastics
- sig(E)/E = 20%/sqrt(E) on other CC events

Spectra and sensitivity is the work of M. Bishai, Mark Dierckxsens, Patrick Huber + many helpers



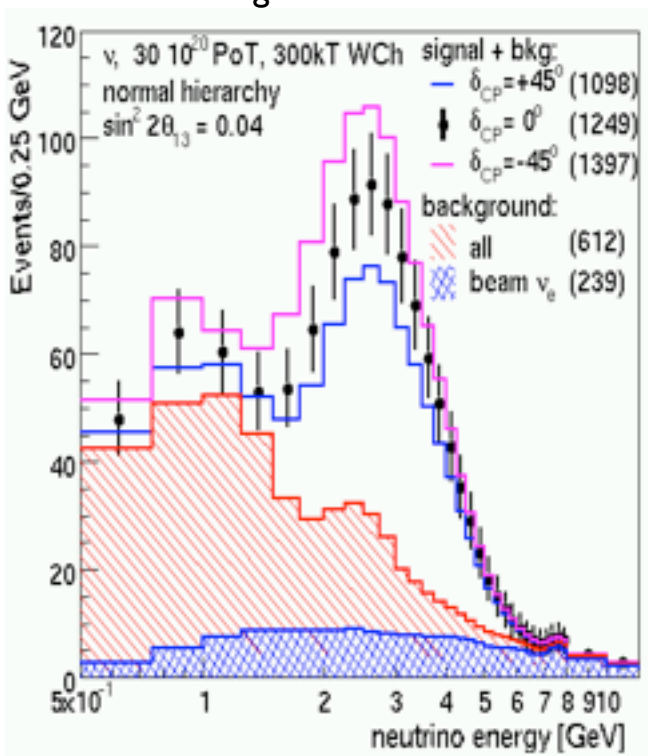
DUSEL beam optimization

Old design
0.5 deg. off. presented last year

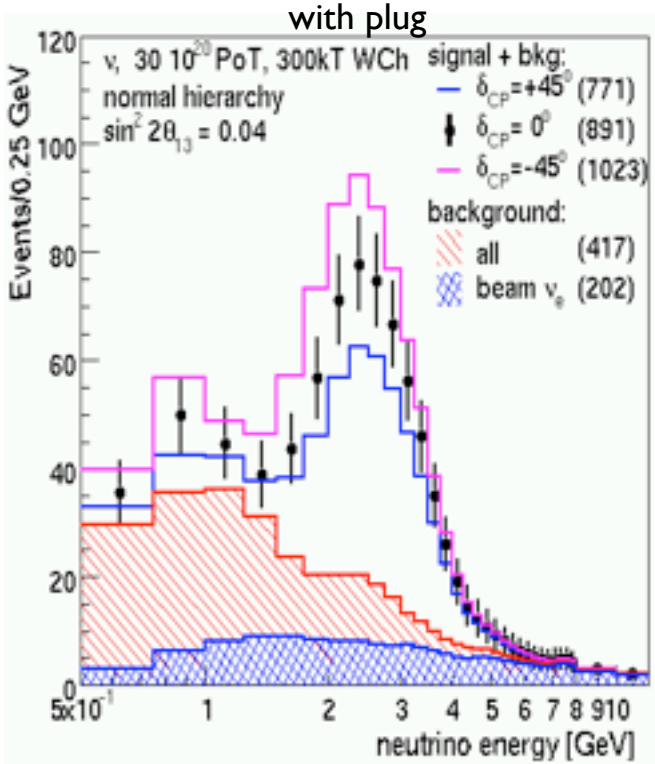


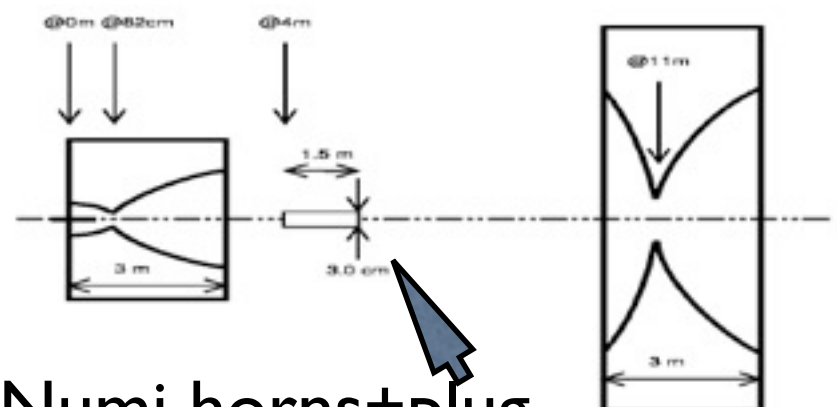
New NuMI based on axis designs and shorter beampipe

High horn current



normal current with plug



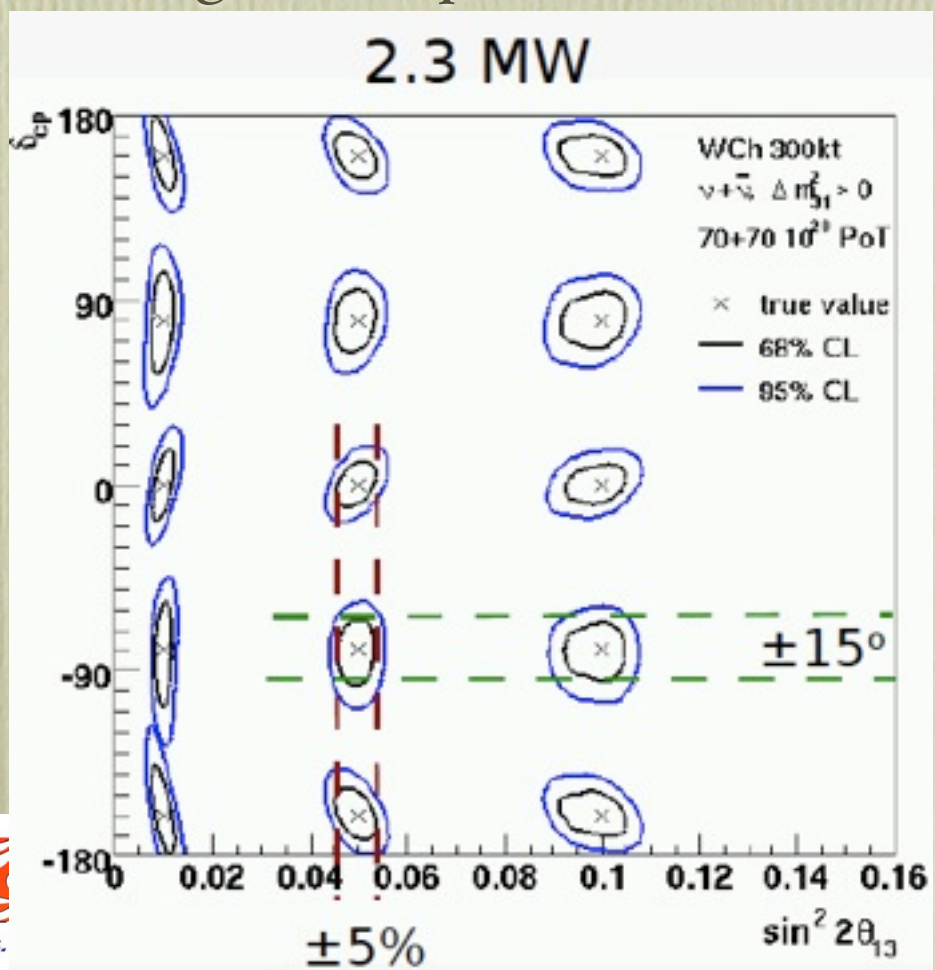


Numi horns+plug

Signal/background enhanced by ~20%. Other optimizations (proton beam energy) under investigation in the beam working group.

Further science issues

- Program should lead to measurement of 3-generation parameters without ambiguities. (recall: CP measurement is approximately independent of θ13). Need large detector independent of θ13 value.
- A broad band beam is needed to get spectral information to resolve ambiguities. Spectrum down to 0.5 GeV important.



300 kT water Cherenkov detector @DUSEL
Measurement of CP phase and $\sin^2 2\theta_{13}$ at several points. All ambiguities and mass hierarchy are resolved.

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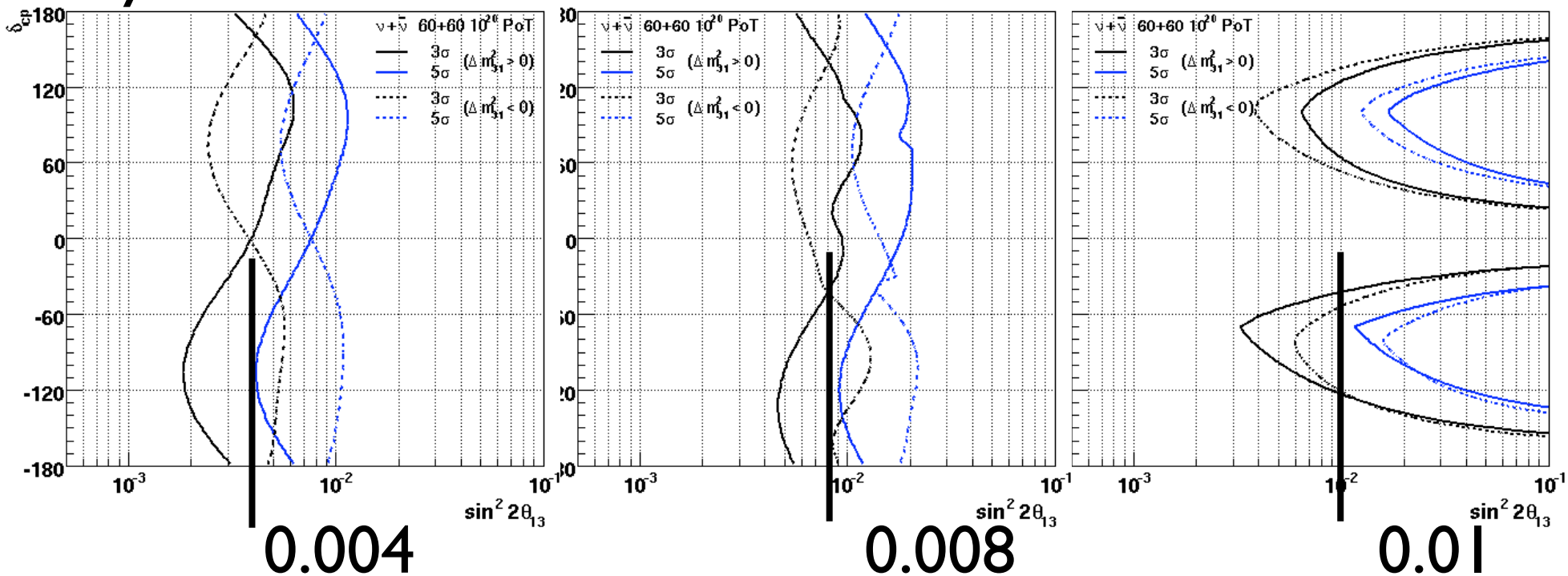
WBLE to DUSEL(1300km) 3sig, 5sig discovery regions.

300 kT WCh Stat+syst

60 10^20 POT for each nu and anu

th13 mass ordering CP violation

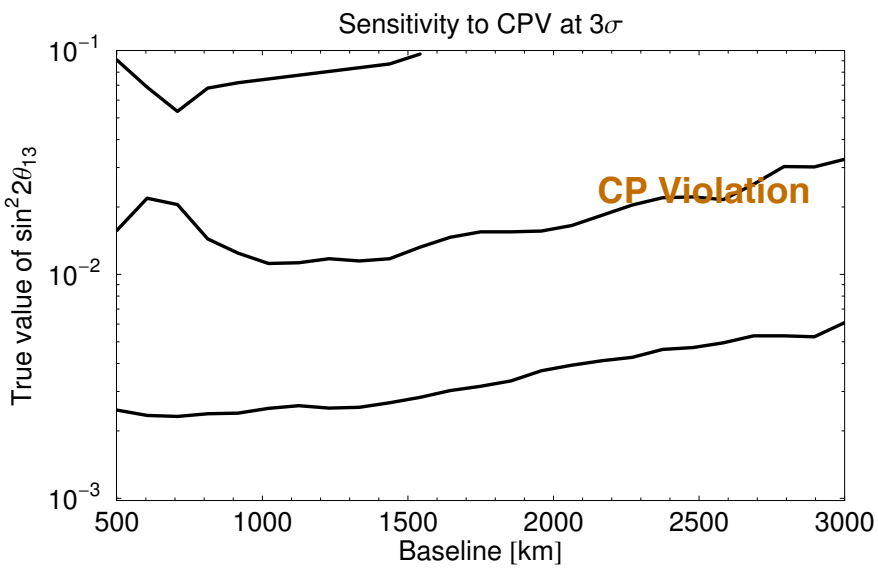


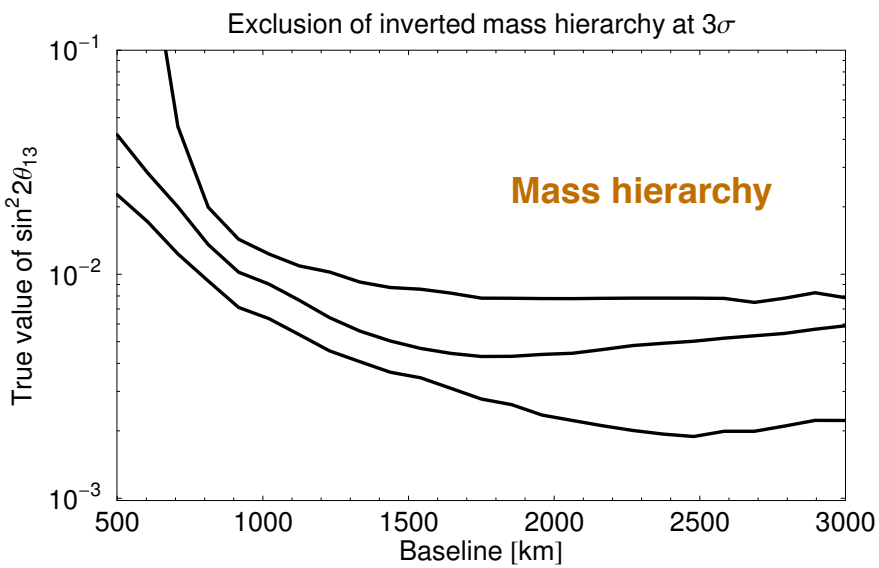
CP Fraction: Fraction of the CP phase (0-2pi) covered at a particular confidence level.

Report the value of th13 at the 50% CP fraction.

Physics sensitivity vs baseline

Using a broad-band beam with peak rate at 2 GeV and a parameterized water Cerenkov detector (V. Barger *et al.*. Phys. Rev. D 74, 073004 2006):





Minimum value of $\sin^2(2\theta_{13})$ for which the sensitivity is $> 3\sigma$

for (best,50%, worst) of δ_{cp} values

Best sensitivity is for baselines 1200 - 2500km

This calculation needs to be updated, but is generically correct.

FNAL beam to DUSEL

- New working group at FNAL
- http://beamdocs.fnal.gov
- Program development public documents.
- Have completed examination of lessons from the NuMI project. This was led by Jeff Appel.

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Neutrino Beam Requirements*

- The maximal possible neutrino fluxes to encompass at least the 1st and 2nd oscillation nodes, which occur at 2.4 and 0.8 GeV respectively
- Since neutrino cross-sections scale with energy, larger fluxes at lower energies are desirable to achieve the physics sensitivities using effects at the 2nd oscillation node
- To detect $\nu_\mu \rightarrow \nu_e$ at the far detector, it is critical to minimize the neutral-current contamination at lower energy, therefore minimizing the flux of neutrinos with energies greater than 5 GeV where there is little sensitivity to the oscillation parameters is highly desirable
- The irreducible background to $\nu_\mu \rightarrow \nu_e$ appearance signal comes from beam generated ν_e events, therefore, a high purity ν_μ beam with as low as possible ν_e contamination is required

**From "Simulation of a Wide-Band Low-Energy Neutrino Beam for Very Long Baseline Neutrino Oscillation Experiments", Bishai, Heim, Lewis, Marino, Viren, Yumiceva*

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The general concept to date

- The present extraction of the Main Injector into the NuMI primary beam-line will be used.
- An additional tunnel will be constructed starting from the approximate location of the NuMI lower Hobbit door, at the end of the carrier tunnel, in order to transport the proton beam to the west.
- The radius of curvature of the tunnel bending west will be similar to the Main Injector curvature which will enable protons with energies up to 120 GeV to be steered along the bend using conventional magnets
- The target hall length is ≤ 45 m.
- A decay tunnel length of up to 400 m can be accomodated on the site assuming the near detector is 300m from the end of the decay pipe.
- The low energy neutrino flux can be enhanced by increasing the decay pipe radius. A radius of ~2 m would be desirable.
- For a ~2MW beam the concrete shielding needed around the decay pipe will be ~2.5m

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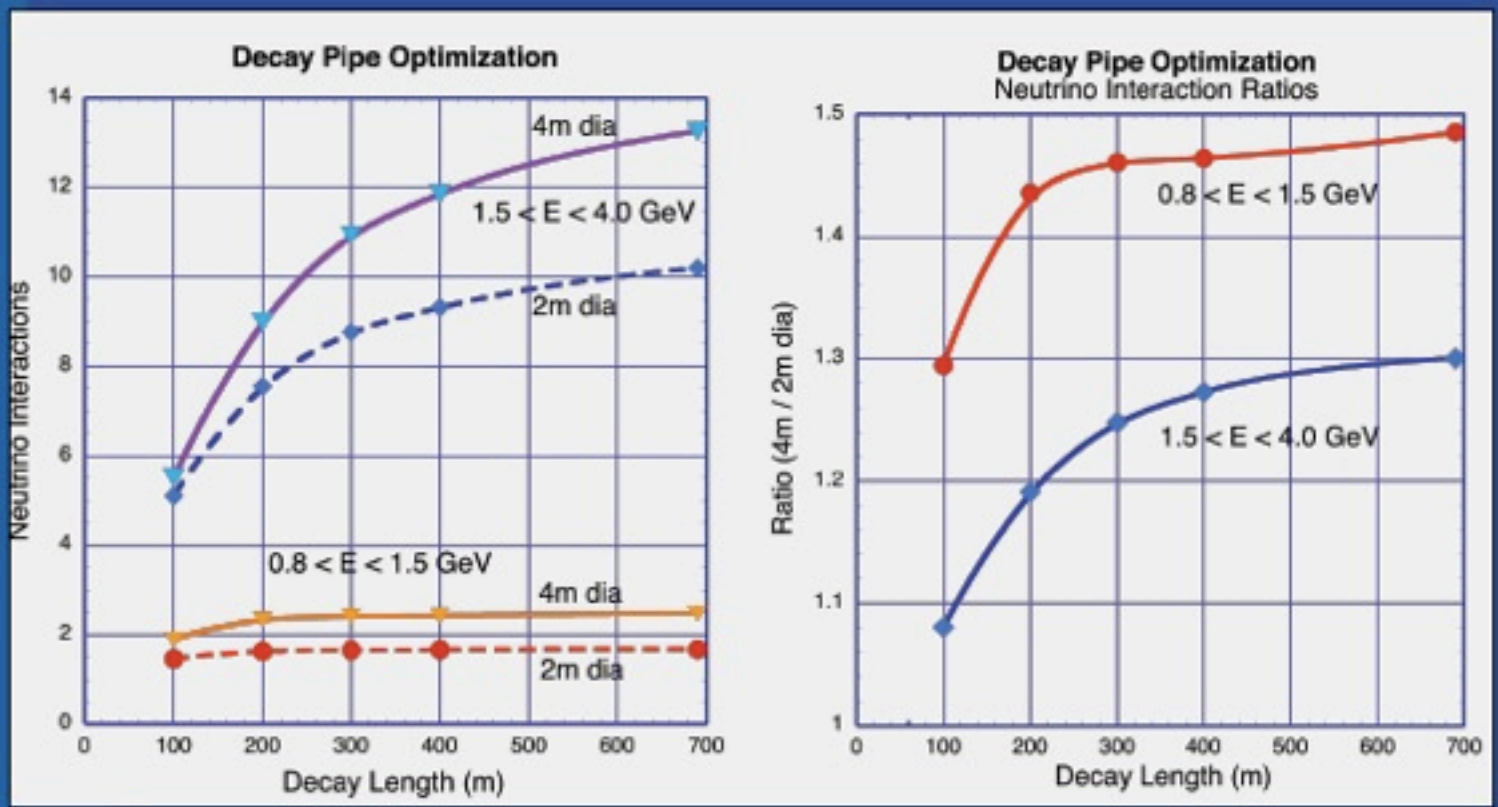
Beam trajectory to Homestake

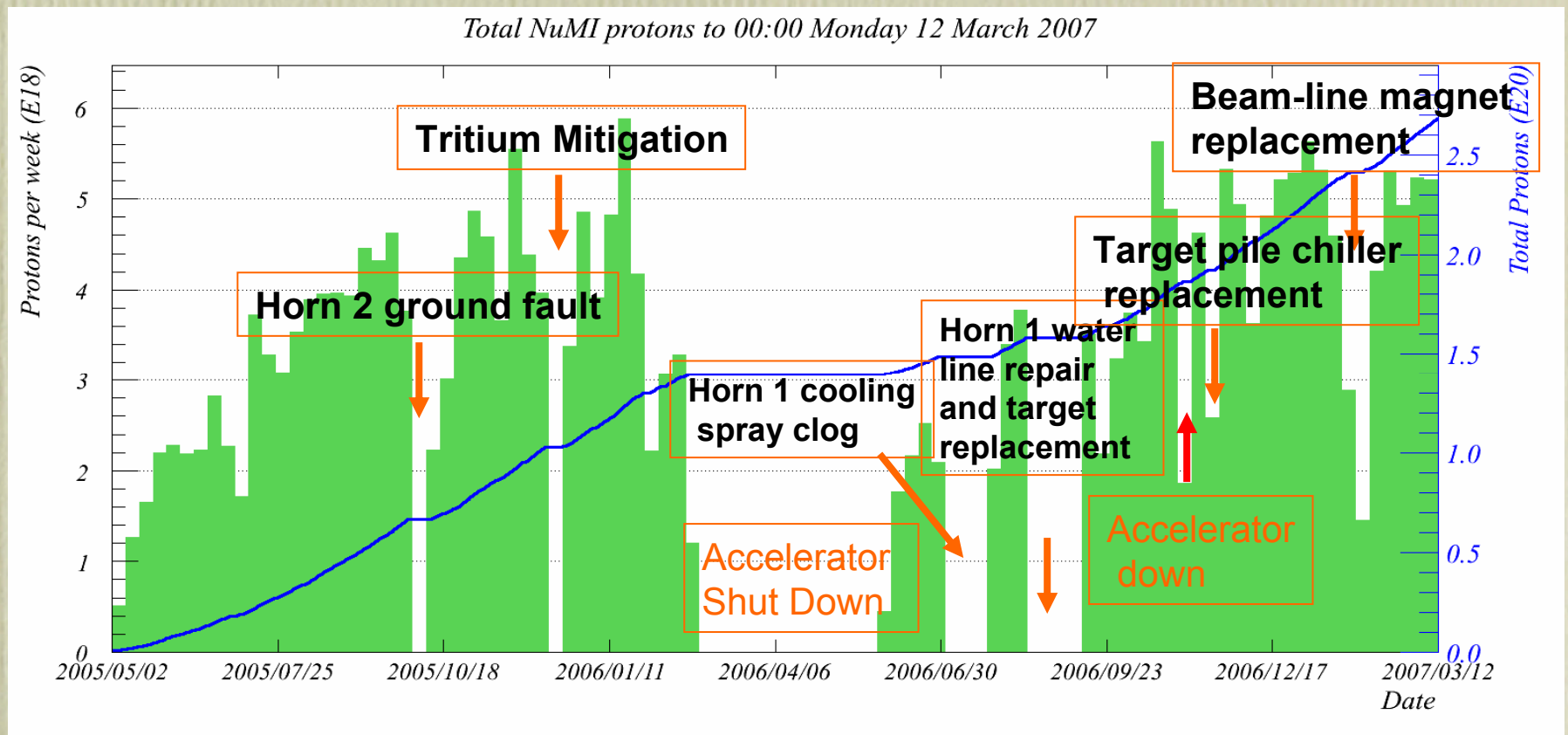
Decay Pipe and Tunnel



NuMI : 2 m diameter pipe, 7m diameter tunnel (shielding and passage), 750 m length

LBNE : 4 m diameter pipe, ~9 diameter tunnel,250 m length

NuMI Performance - POT/week



We need exposures that are >10 times higher for FNAL-to-DUSEL. We now have all the relevant experience to do it.

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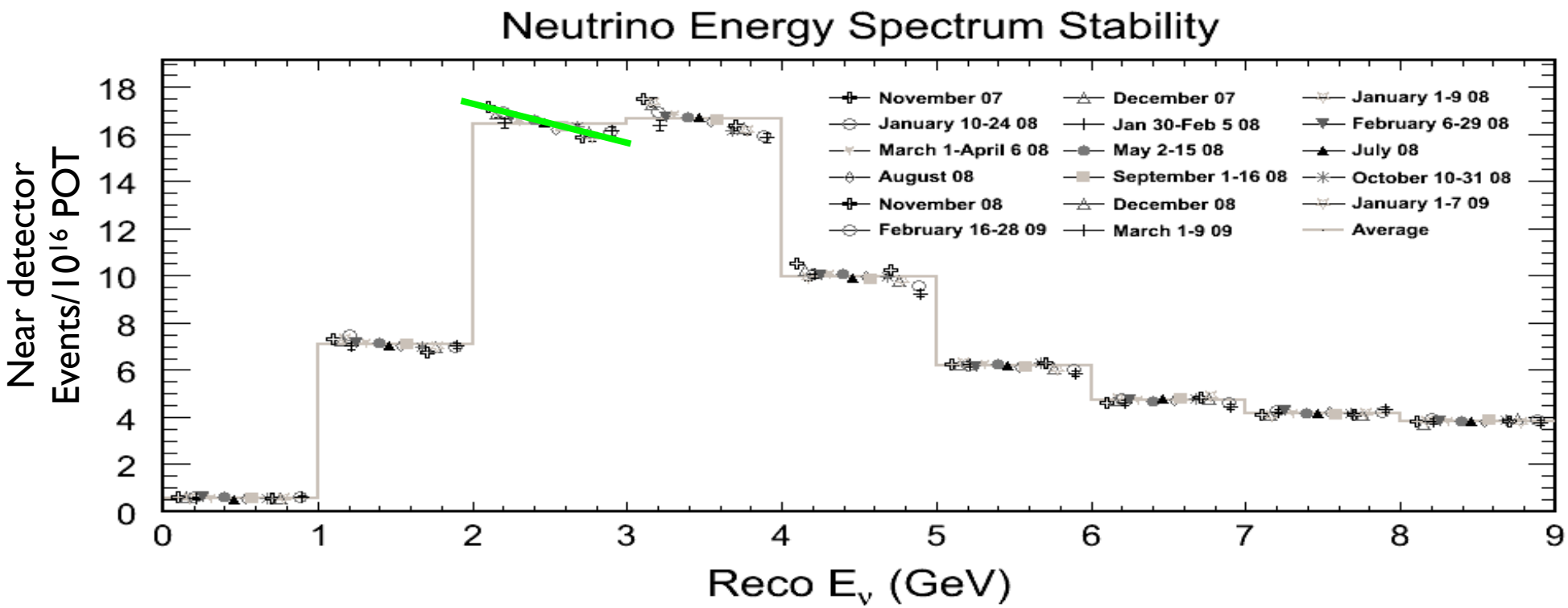
NuMI knowledge base is excellent

Up (513) and down (83) days 5/1/05 - 3/22/07

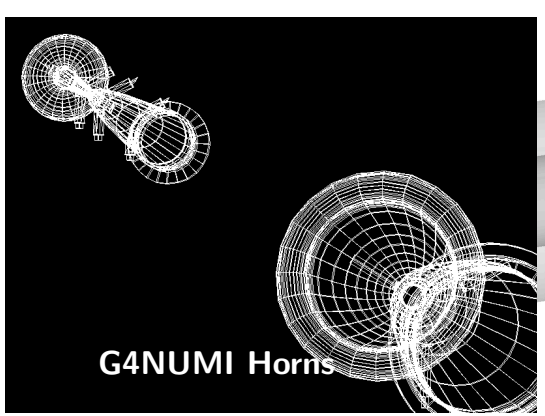
86% / 74% efficiency excluding / including sched. shutdown

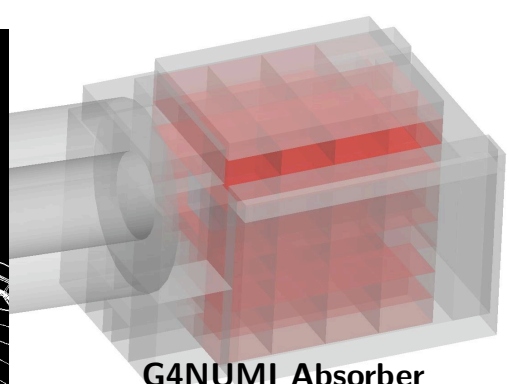
Days	Description (**non-recurring)		Long term corrective action
513	Up for beam		
95	Accelerator scheduled down		
25	Horn cooling spray clog **		Check valves, filters on skids
14	Horn water line repair		Eliminate braze on spares
14	Target motion frozen		Graphalloy bushing on spare
10	Horn ground fault		Pin feet, float modules
8	Tritium mitigation **		Condensate sys./dehumidifiers
6	Replace NuMI beam-line magnet		
4	Replace accelerator magnet		
2	Replace pile chiller compressor		New hot spare chiller unit

MINOS Precision Beam Work



FLUGG = G4NuMI geometry + FLUKA08 unified interaction/focusing simulation





- Slow decrease in event rate seen at the peak, perhaps due to target degradation.
- Extremely precise simulation work now in progress.
- Will be based on data
- Will have broad applicability.

NuMI Extraction from MI

The MI accepts up to 6 proton batches ($\sim 5 \times 10^{12} p$/batch) at 8 GeV from the Booster, accelerates $8 \rightarrow 120$ GeV in ~ 1.5 s. MI cycle types:

NuMI only: Every 1.9 seconds.

Batches 1-6 $\rightarrow$ NuMI in 10 μ s

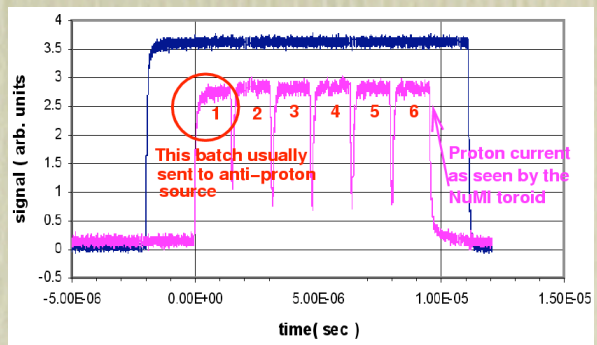
Mixed mode: Every 2.4-4 seconds.

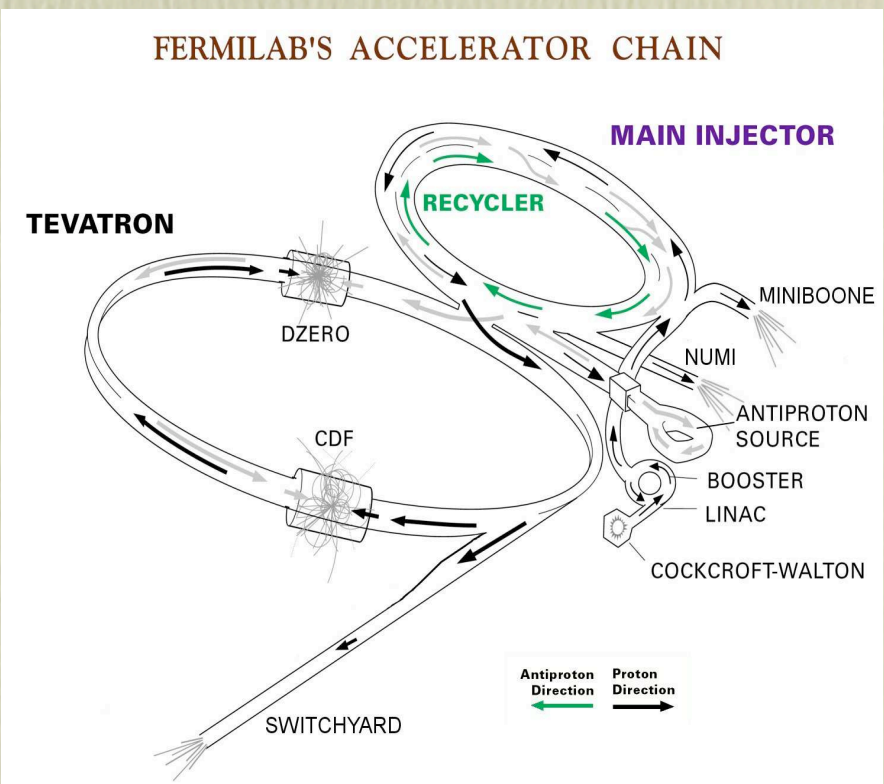
Batch "1" (2 merged Booster batches "slip stacked" at 8×10^{12} p) $\rightarrow$ $\bar{p}$ source.

Batches 2-6 $\rightarrow$ NuMI in 8 μ s.

Tevatron store cycles:Once per day (~ 2 hrs). 150 GeV $p \rightarrow$ Tevatron and $\bar{p}$ from Pbar source accelerated to 150 GeV and injected into Tevatron.

Batch structure as measured in NuMI beamline

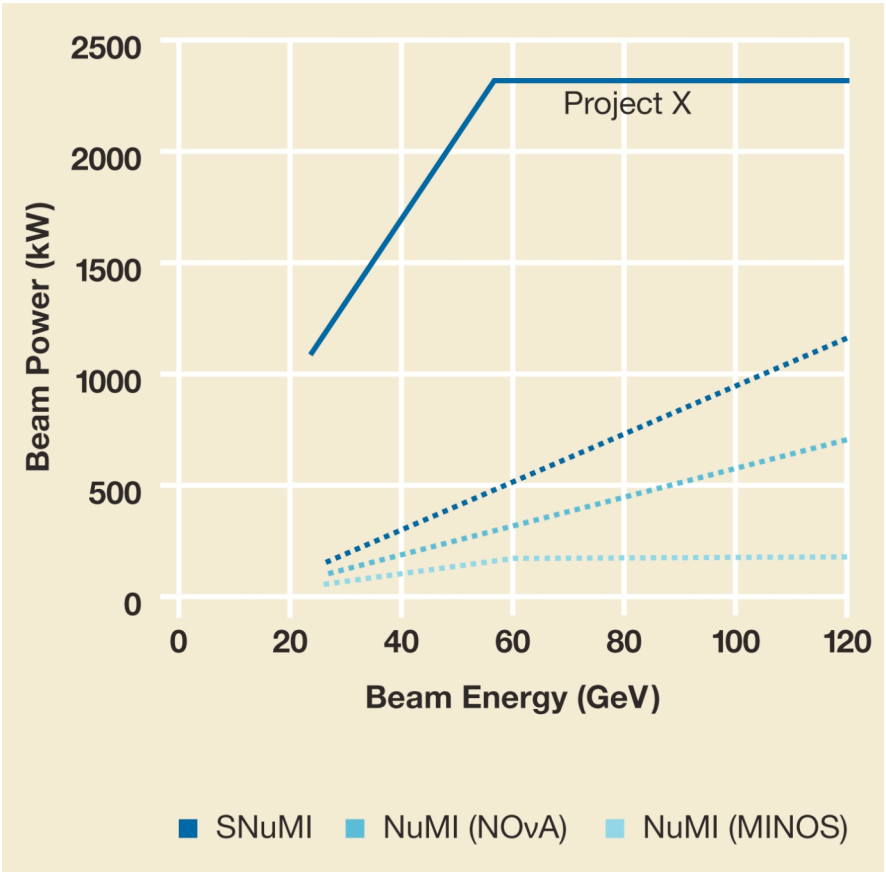




	Protons (10^{12})	Cycle time (sec)	Power (kw)
Current complex No improvements			
- Shared beam	25	2.4	200
- NuMI alone	30	2.0	280
Proton plan Slip-stacking			
-Shared beam	37	2.2	320
-NuMI alone	49	2.2	430
SNuMI -Recycler slip-stack; reduce cycle	49	1.33	700
SNuMI -Accumulator momentum stack;	82	1.33	1200
High Intensity Source 8 GeV SC LINAC injector (maj. upgrades to MI-RF)	150	1.33	2200

SNuMI: depends on the current booster

- 60 -120 GeV protons from the Main Injector fed by Project X



20-40x10^{20} POT/yr

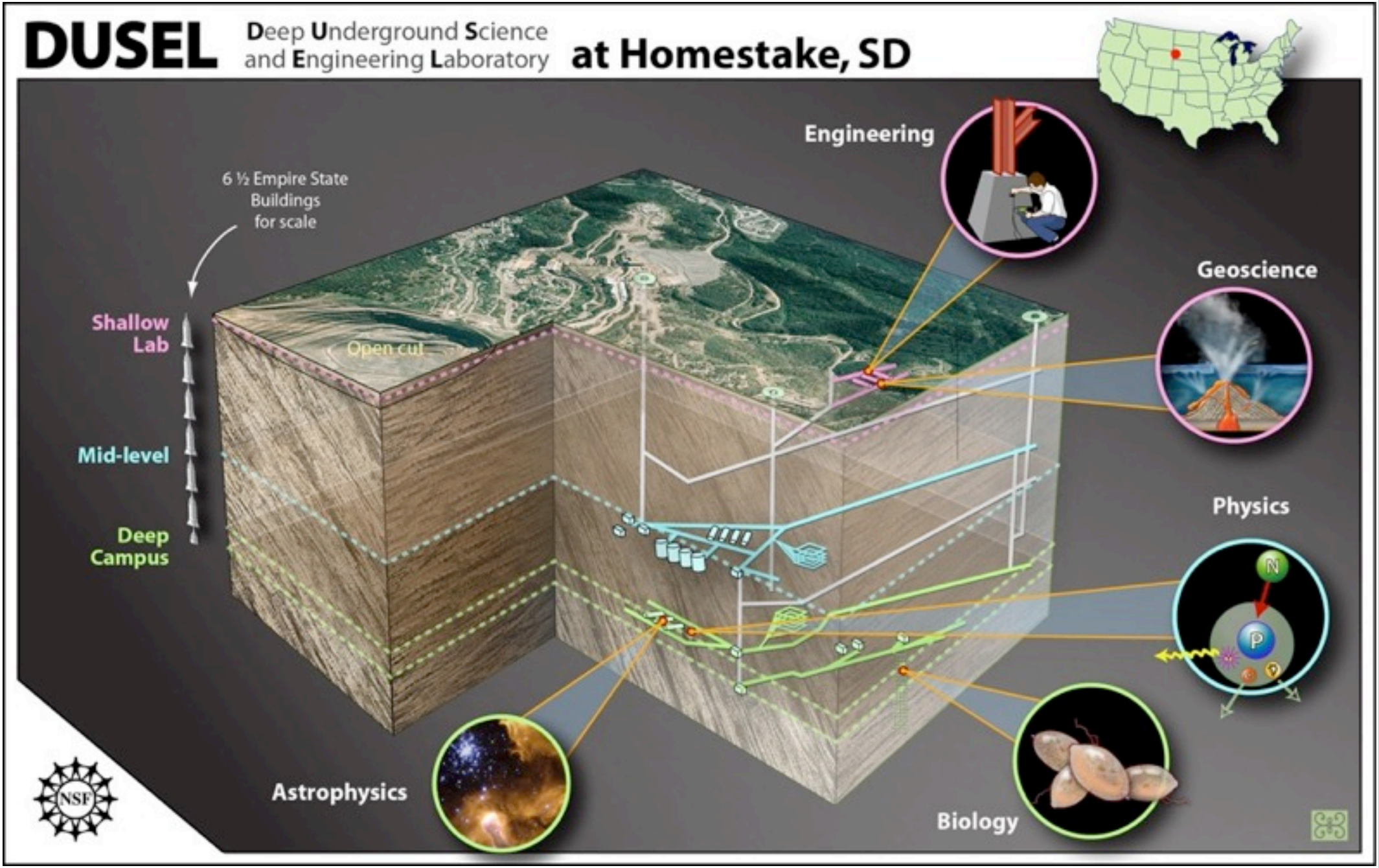
10x10^{20} POT/yr

6x10^{20} POT/yr

3x10^{20} POT/yr

Recent sensitivity studies are being done for 120x10^{20} POT each ν and $\overline{\nu}$ (120 GeV)

$$POT(10^{20}) = \frac{1000 \times BeamPower(MW) \times T(10^7 s)}{1.602 \times E_p(GeV)}$$

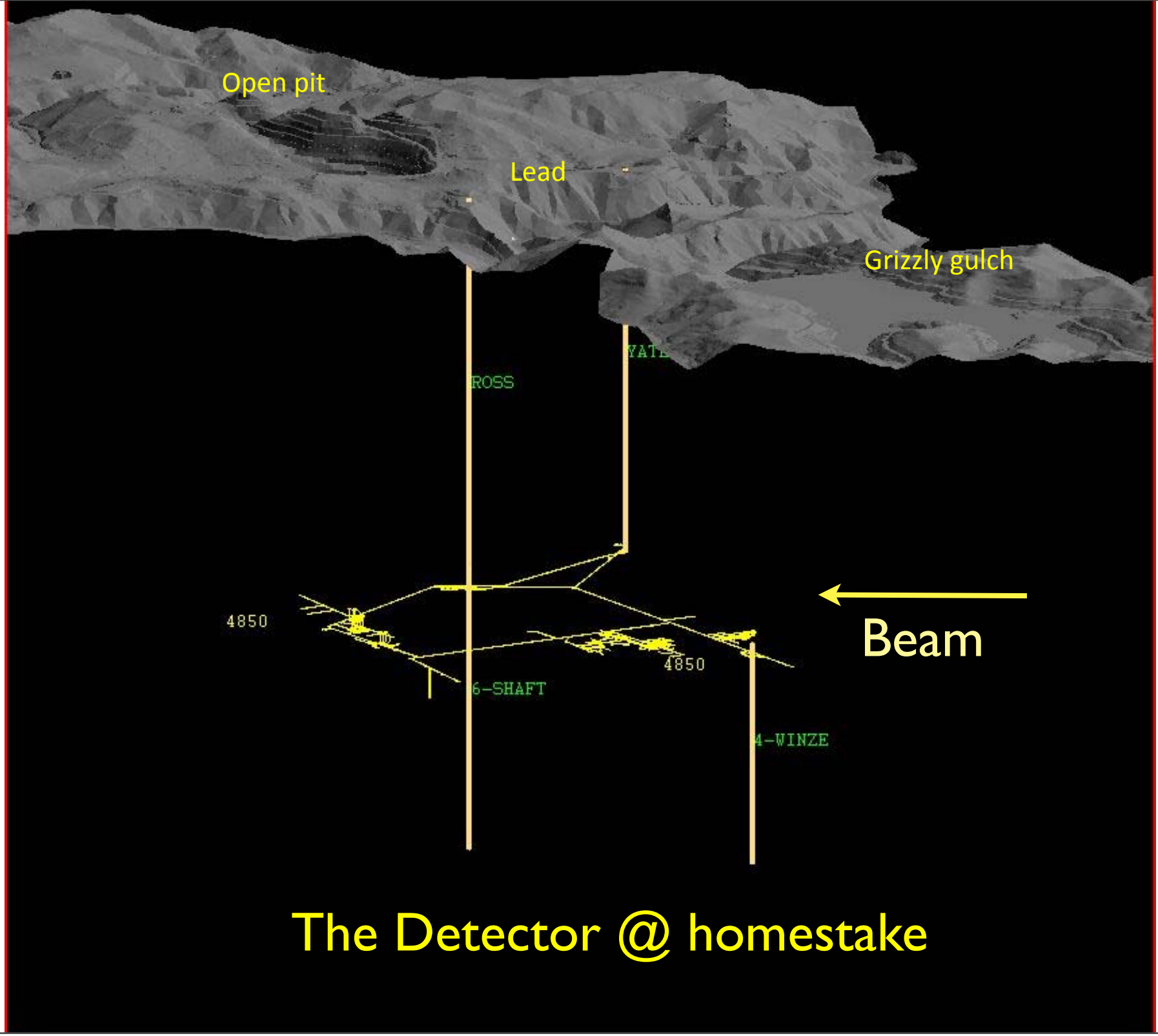


NSF site decision on advice from a 22 member unanimous panel.

Where is S. Dakota ? What are black hills ?

SD has Tradition of mining

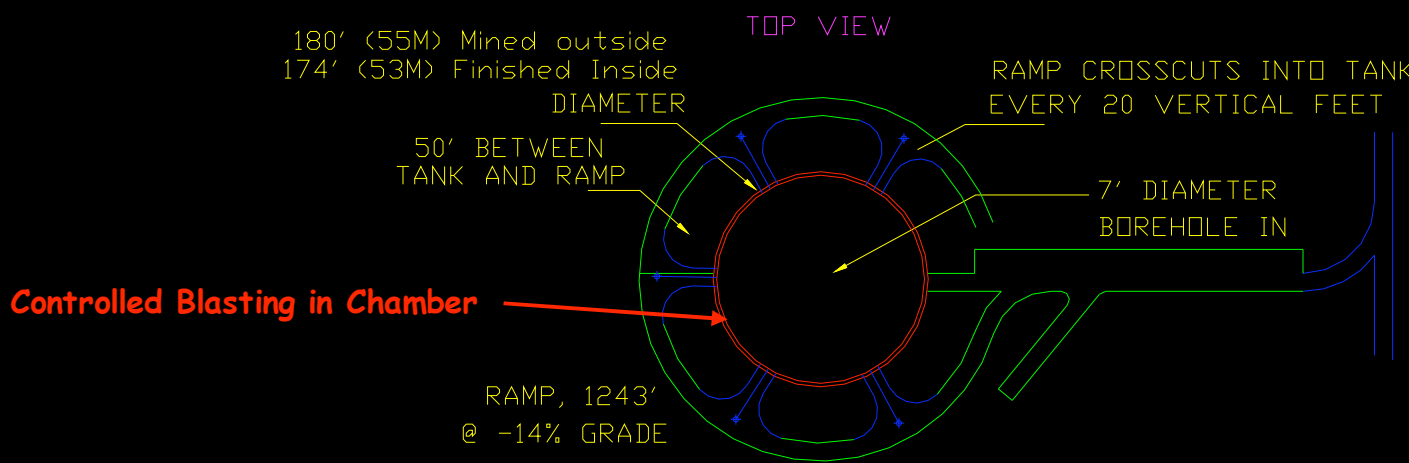
- South Dakota is West of Wisconsin (take I-90)
- Black hills are better than the South Pole



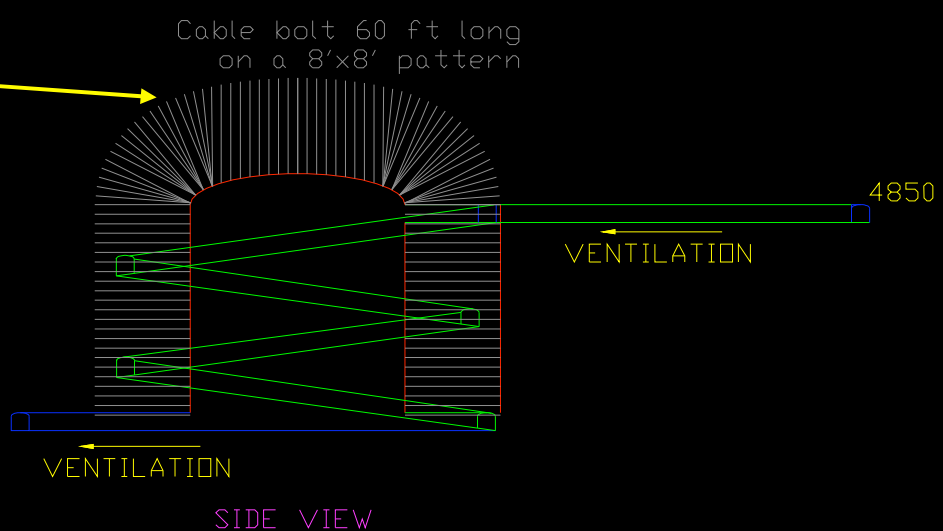
The Detector @ homestake

MEGATON MODULAR MULTI-PURPOSE NEUTRINO DETECTOR

✓ Chamber Design



Could use Instrumented Cables for Engineering / Geotechnical Study



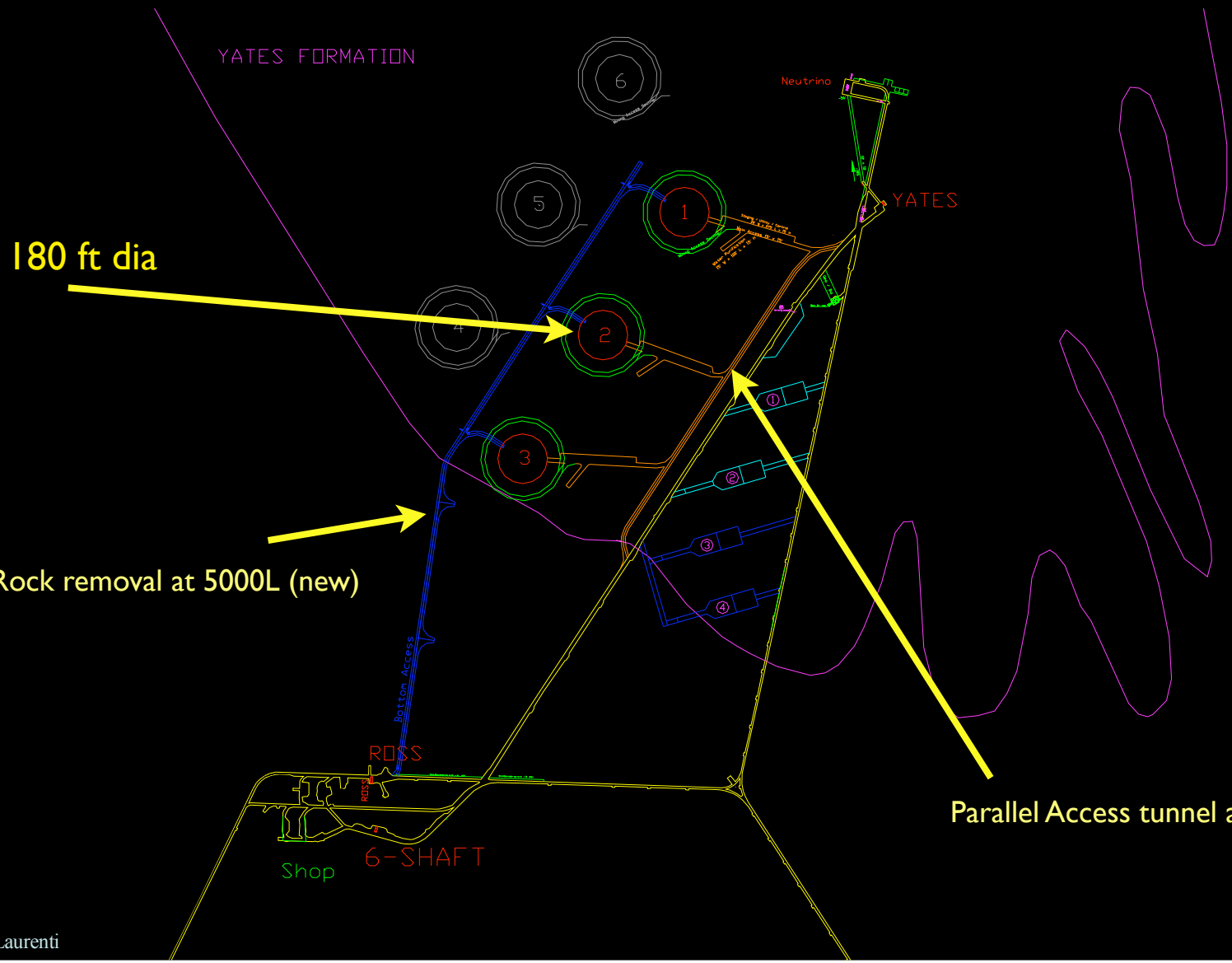
Mark A. Laurenti (Former Homestake Chief engineer)

November 2007

Megaton Modular Multi-Purpose Neutrino Detector

✓ **Modular Configuration**

muon rate/cavern 0.1-0.3 Hz



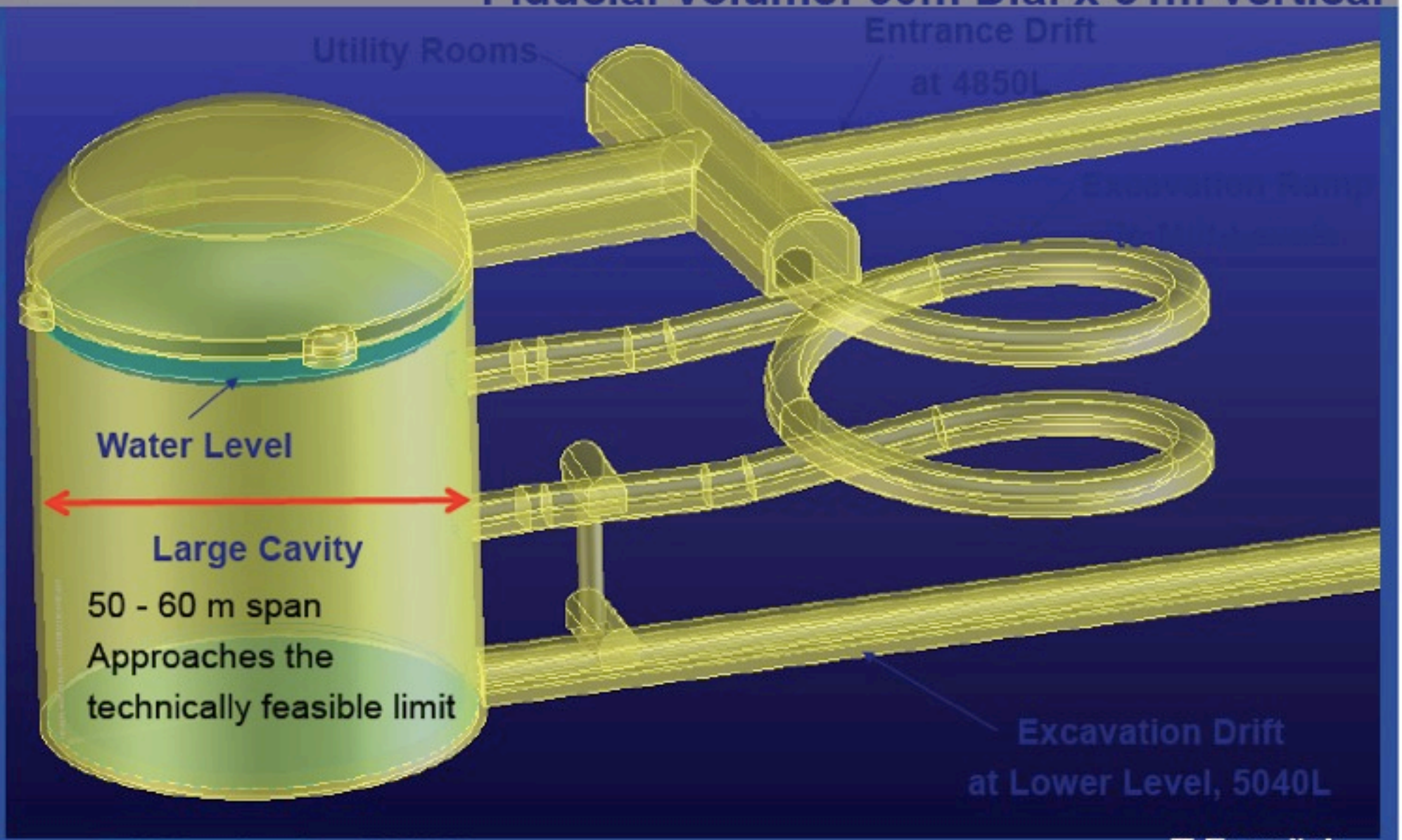
Mark A. Laurenti

November 2007

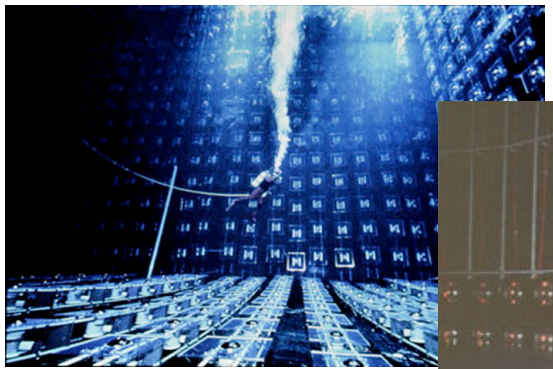
Large Cavity, Water Cerenkov Detector

Water: 53m Dia. x 54m vertical,

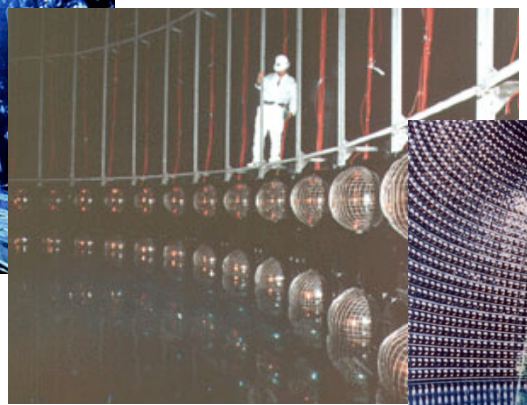
Fiducial Volume: 50m Dia. x 51m vertical



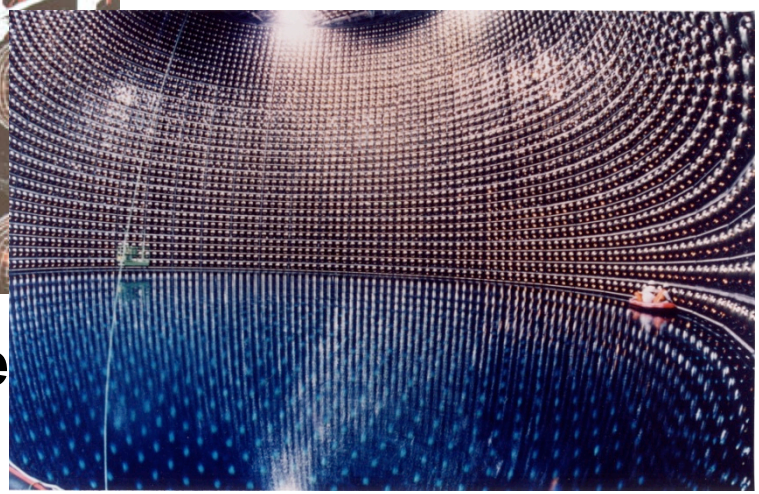
Water Cherenkov Detector



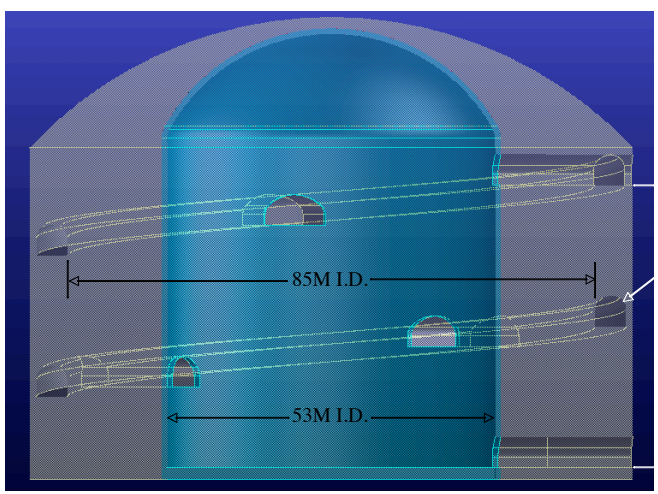
IMB
3 ktons



Kamiokande
1 kton



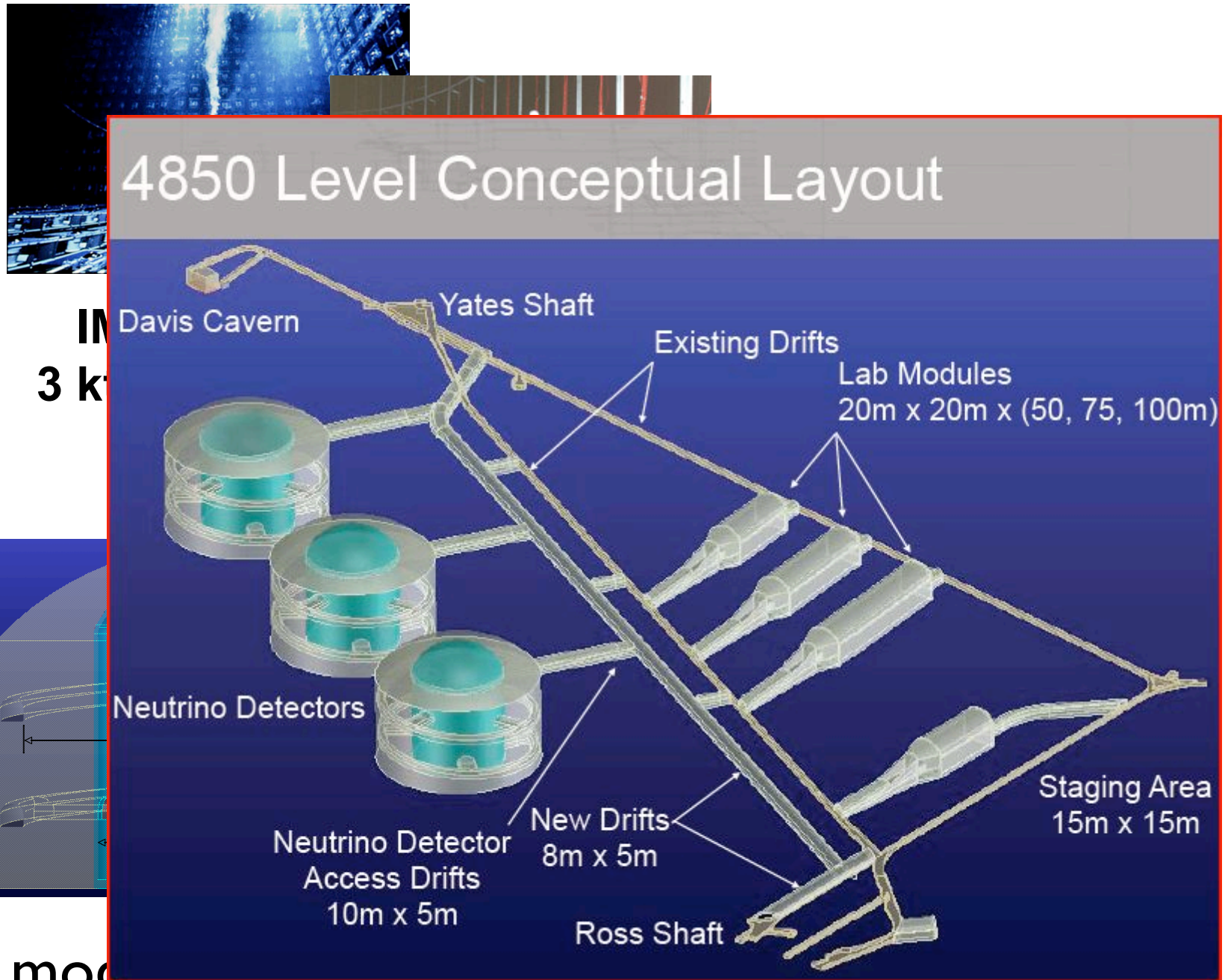
Super-Kamiokande
22 ktons



1 module fid:100 kT

300 kT

Water Cherenkov Detector



300 kT

PMT R&D

- Issues are: making 150000 tubes in 6 years time, their efficiency, and their pressure performance.
- If PMTs can stand higher pressure, the cavern can be taller => more fiducial volume.
- Have had meetings with Photonis and Hamamatsu: no barrier to PMT production except money.

PMT considerations

	10 inch R7081	20 inch R3600
Number (25% cov)	~50000	~14000
QE	25%	20%
CE	~80%	~70%
rise time	4 ns	10 ns
Tube length	30 cm	68 cm
Weight	1150 gm	8000 gm
Vol.	~5 lt	~50 lt
pressure rating	0.7Mpa	0.6Mpa
$\star$ coverage/pmt	0.6 deg	1.1 deg
$\star$granularity	1.0 deg	2.1 deg

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PMT: further choice

Items	Example 12-inch PMT	R7081 10-inch PMT	R5912 8-inch PMT
Diameter	300 mm	253 mm	202 mm
Effective Area	280 mm min.	220 mm min.	190 mm min.
Tube Length	330 mm	245 mm	220 mm
Dynodes	LF/10-stage	LF/10-stage	LF/10-stage
Applied Voltage	1500 V	1500 V	1500 V
GAIN	1.00E+07	1.00E+07	1.00E+07
T.T.S.(FWHM)	2.8 ns	2.9 ns	2.4 ns
P/V Ratio	2.5	2.5	2.5
Dark Counts	10,000 cps	7,000 cps	4,000 cps

NEW !

HAMAMATSU
HAMAMATSU PHOTONICS K.K. Electron Tube Division

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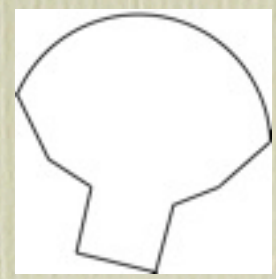
Tube production

Glass

Stamped metal and wire parts

First assembly
vacuum deposition of metal platings
Graded seal



Final vacuum
Cathode deposition

Final assembly of 10 inch tubes needs lab space of 30'x30'; six stations with 6 pmts/station; 1 full day => 36tubes/day = icecube production. tripling this rate is not difficult

HPK is NOT concerned about their ability to manufacture at this rate

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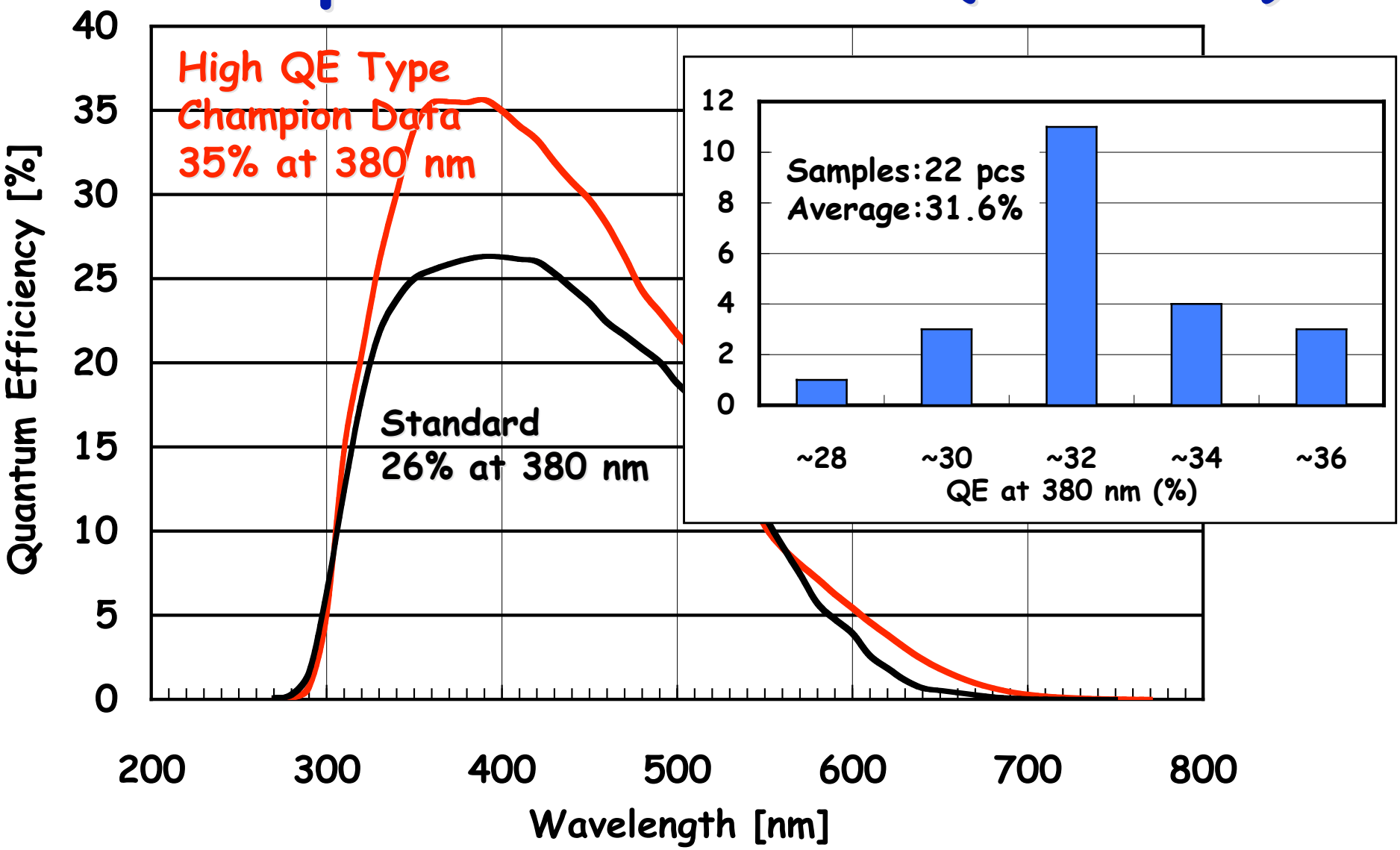
Example data R7081 (10 inch)



Goal of development is 43%

M.Diwan

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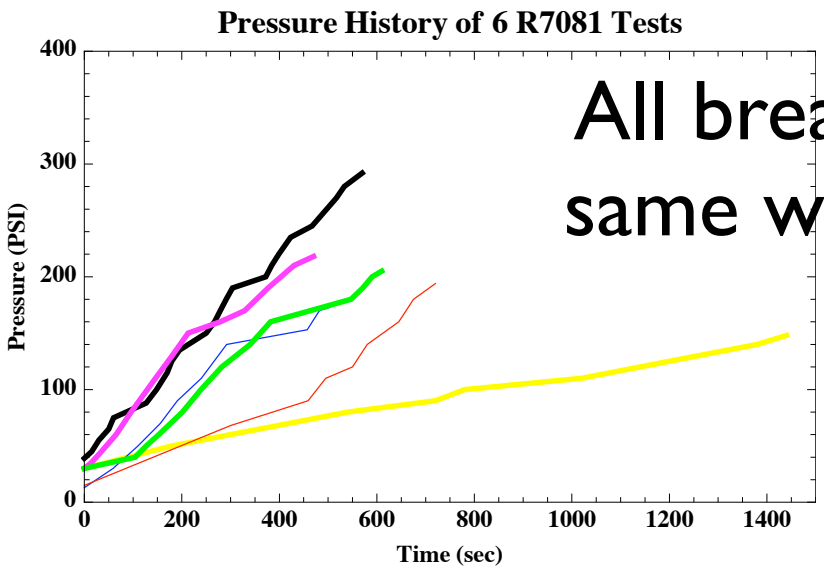
Baseline Plan

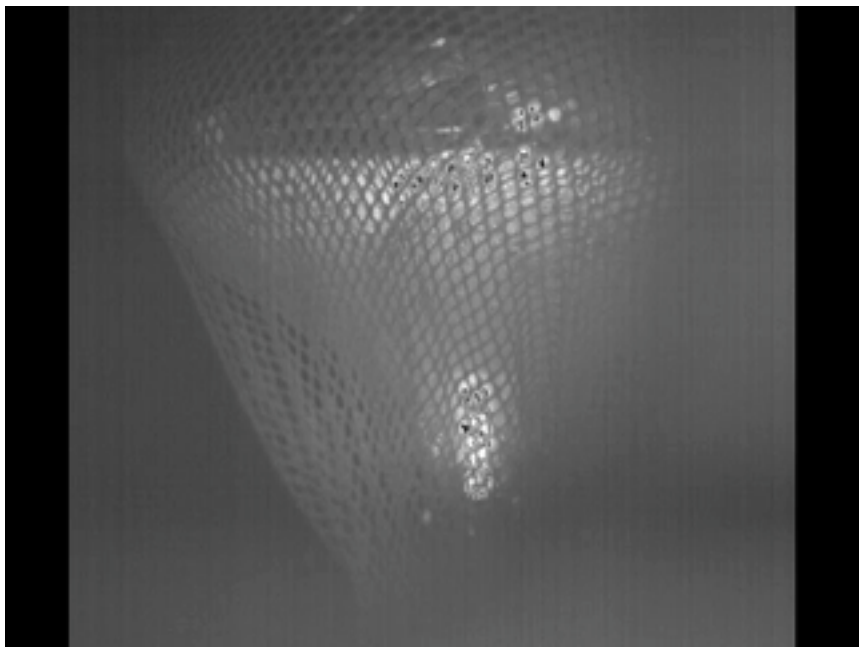
- The Baseline plan is R7081 with 25%cov*25%QE(Learned recently that high QE can be made at same rate).
- The correct number to look at is Coverage*QE*Collection eff.
- We will need 50000 to 70000 per chamber depending on shape to obtain similar amount of light collection as SK.
- R7081 has been used by Icecube. There is also production for other projects.
- Only issue for us is pressure performance.

Work on pressure performance

- Pressure at implosion
- Implosion process. (fast motion movie), photos
- Pressure pulse



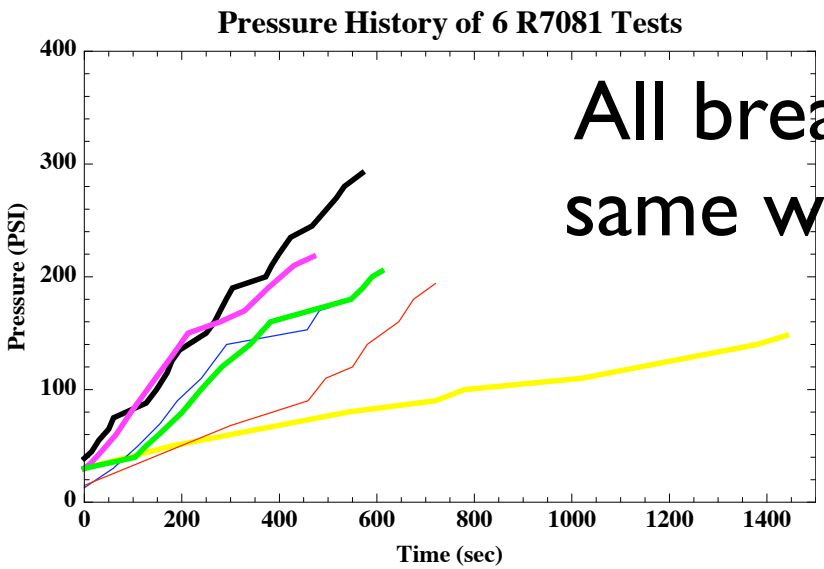
All break same way



Breakage at pins

Work on pressure performance

- Pressure at implosion
- Implosion process. (fast motion movie), photos
- Pressure pulse



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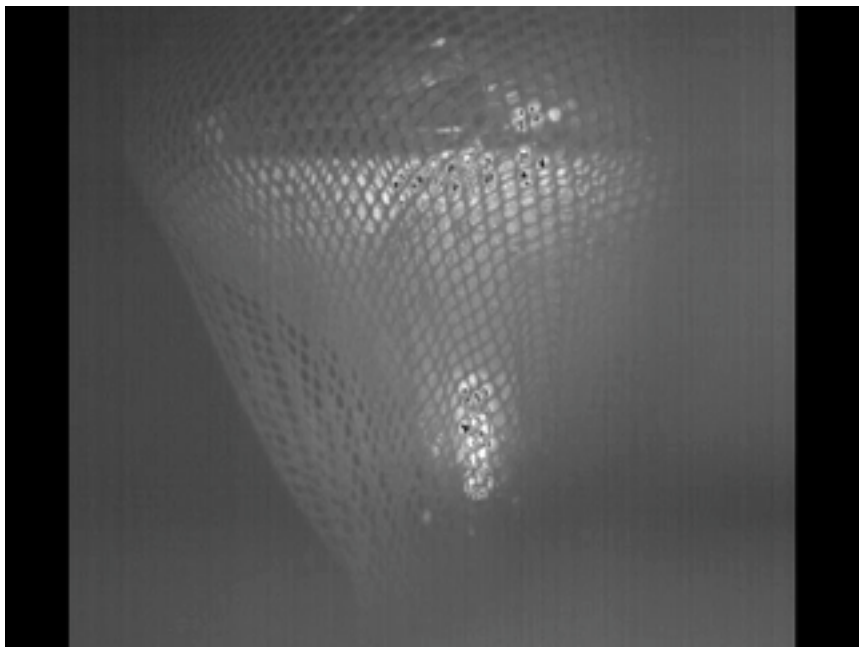

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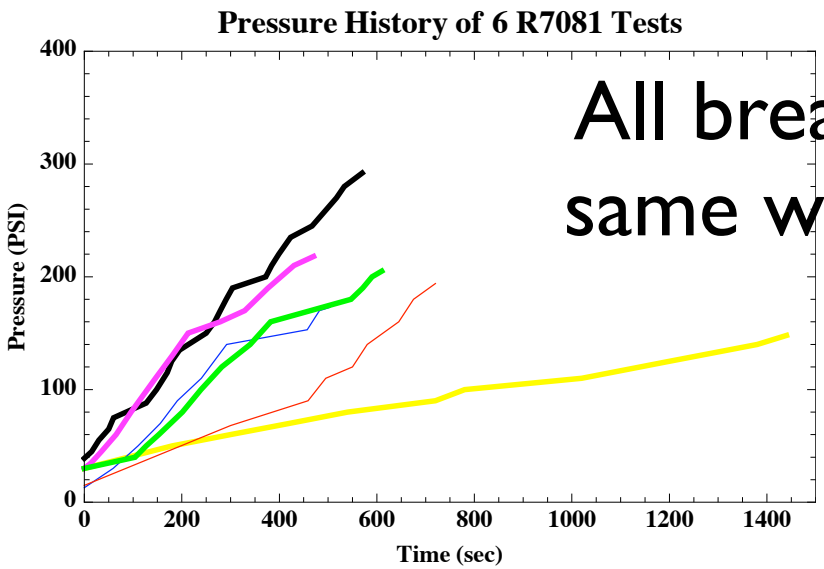

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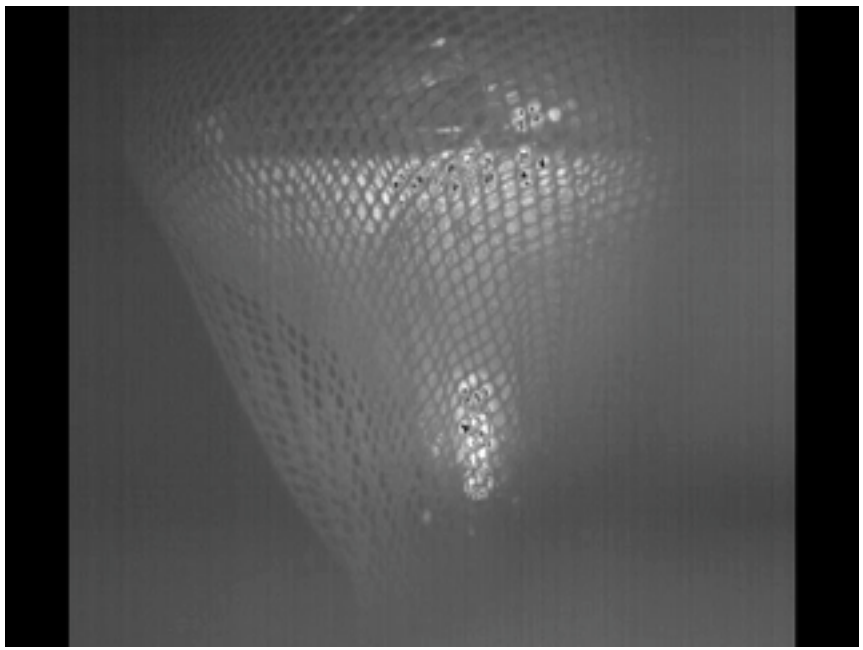

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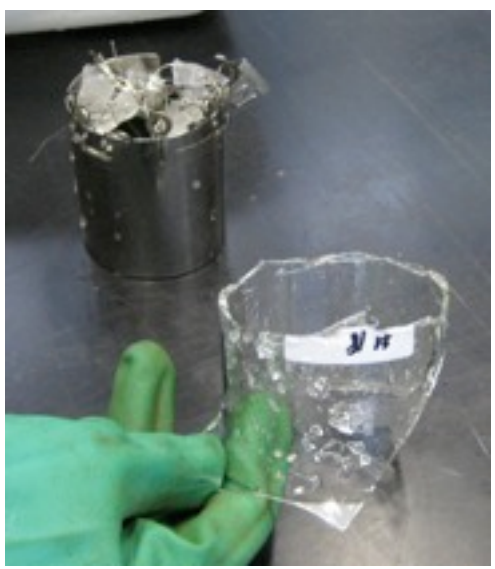

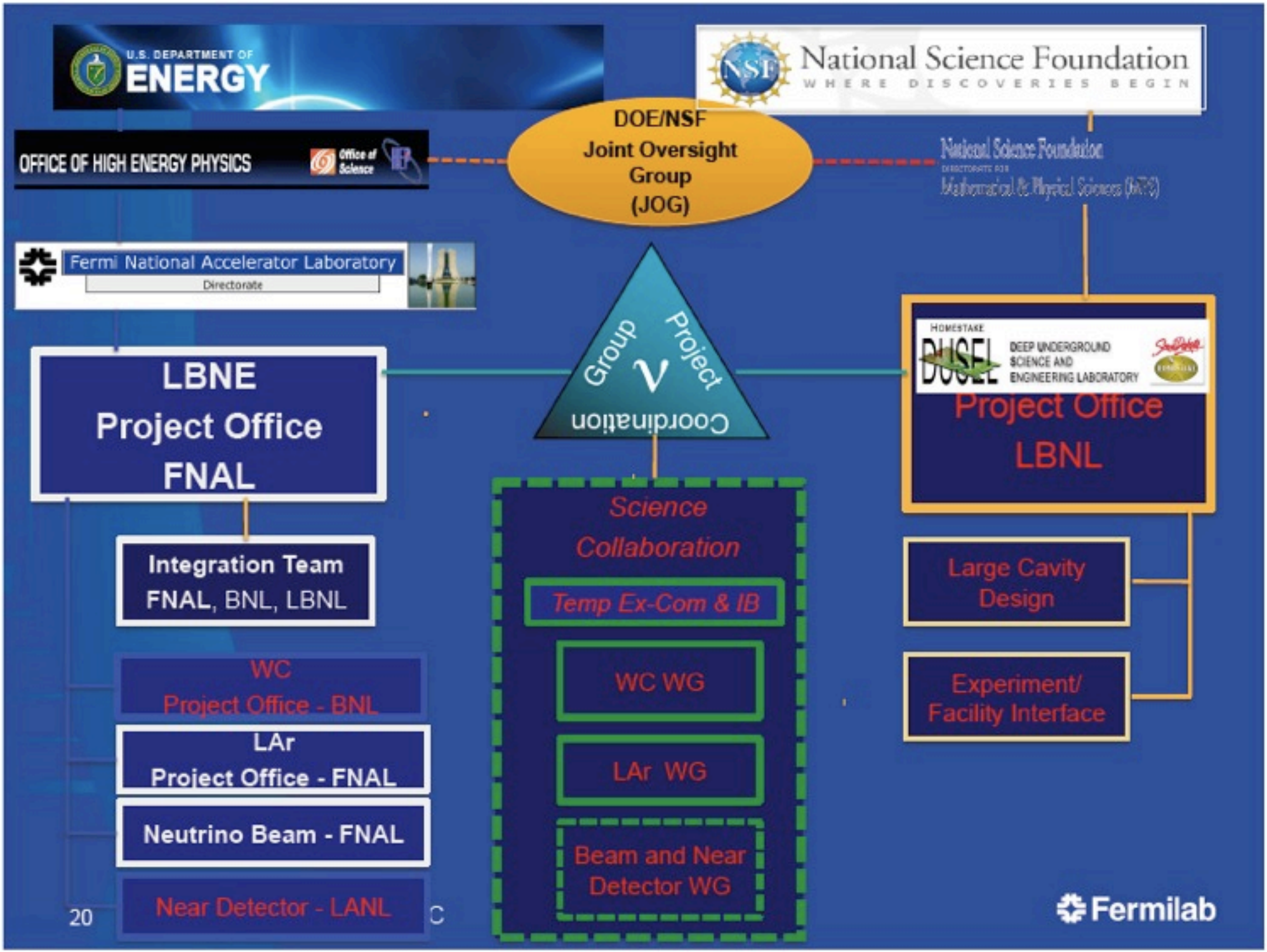
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Project Office
LBNL
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FNAL, BNL, LBNL
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LAr WG
Beam and Near
Detector WG
Large Cavity
Design
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Facility Interface
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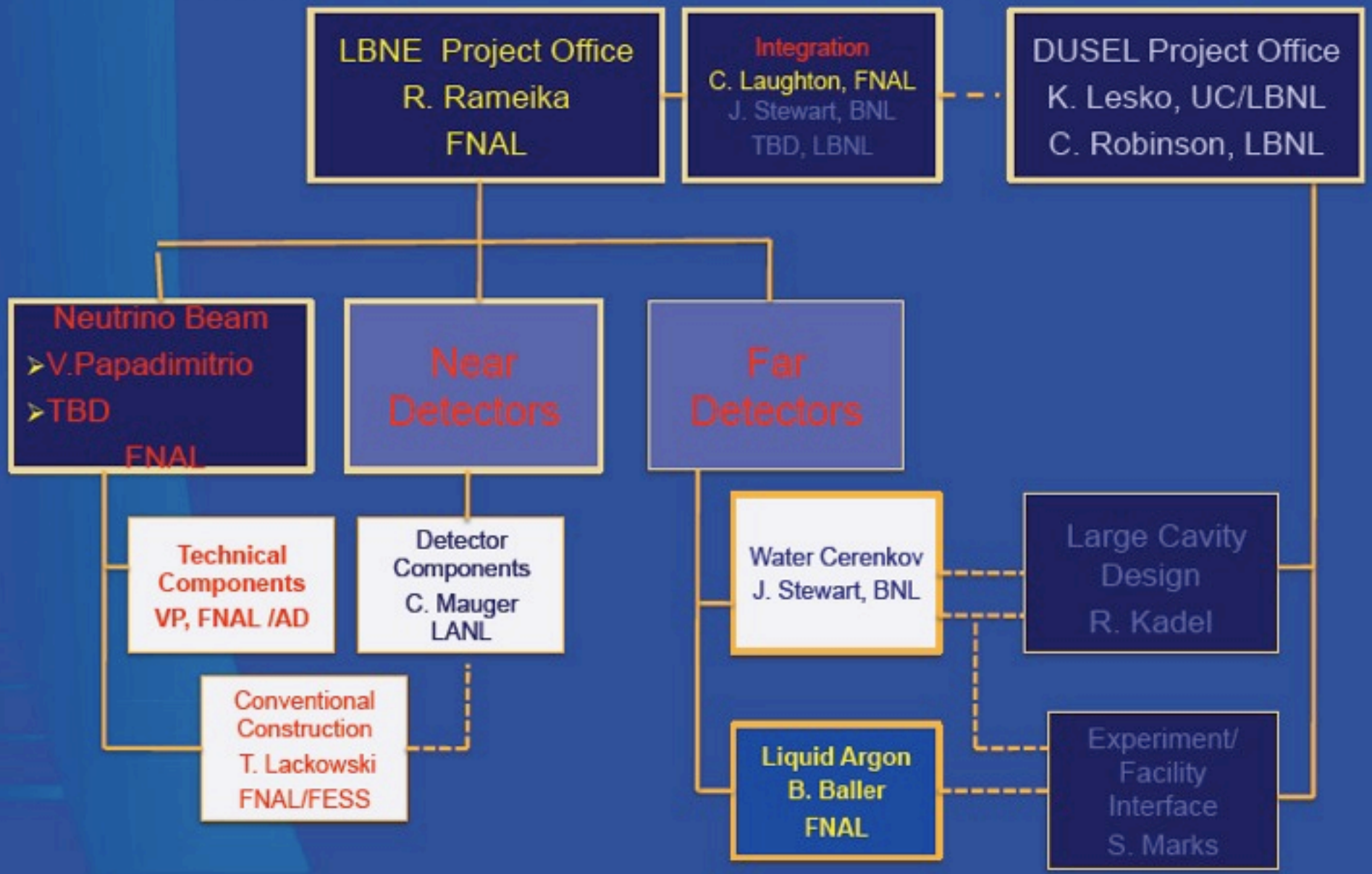
LAr
Project Office - FNAL
Neutrino Beam - FNAL
Near Detector - LANL
20
Fermilab

LBNE : Project Definition Phase (pre CD-0 – CD-1)



Fermilab

Status

- Project is big, and must follow big-project-procedure. This can be fast: e.g. NSLS-2 (~$1 b) at BNL went from CD0 to CD2 in 3 yrs.
- Mission Need Docs for CD0 is prepared and is under review in DOE.
- Project Management teams at FNAL and BNL are being staffed.
- A plan for developing CD1 docs has been developed and handed over to DOE. LBNE doc 26-v2.
- $15 ARRA funds is going to LBNE to speed up CD0 to CD1 process.
- CD1 review at end of FY2010, reviews every 6 moths.
- Science collaboration awaiting funding from NSF S4 and some DOE supplements.

Conclusion

- A 300kT detector at a good depth is well justified for accelerator neutrino physics.
- If built in the USA it has unique and complementary physics capability in the world due the length of the baseline.
- A conventional beam from FNAL to Homestake lab. is going through an examination by a technical working group.
- Excellent sensitivity for θ_{13} and mass ordering and CP violation. Non-accelerator physics additional.
- The caverns built could house different technology: better PMTs, Liquid Scintillator, Liquid Argon ...

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